

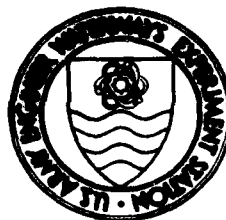


US Army
of Engineers

AD-A144 111

T

—
—



June 1984
Final Report

Approved For Public Release; Distribution Unlimited

DTIC
ELECTE
AUG 7 1984
S D A

DTIC FILE COPY

Prepared for Defense Nuclear Agency
Washington, DC 20305

and DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314

Under DNA Subtask Y99QAXSC, Work Unit 00080

and OCE R&D Project 4A762719AT40,
Task AO, Work Unit 008

84 08 00 000



**Destroy this report when no longer needed. Do not
return it to the originator.**

**The findings in this report are not to be construed as an
official Department of the Army position unless so
designated by other authorized documents.**

**The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of such
commercial products.**

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

The preparation of this report was sponsored by the Defense Nuclear Agency (DNA) under Subtask Y99QAXSC, Work Unit 00080, "Key Worker Shelter," and by the Office, Chief of Engineers, U. S. Army, under R&D Project 4A762719AT40, Task AO, Work Unit 008, "Target Response from Low-Yield Nuclear Surface and Subsurface Bursts." Dr. K. L. Goering, DNA, was Technical Monitor.

This report was prepared at the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. James T. Ballard, Acting Assistant Chief, SL, and under the direct supervision of Dr. Jimmy P. Balsara, Acting Chief, Structural Mechanics Division (SMD), SL. This paper was prepared by Mr. L. K. Guice, Associate Professor, Louisiana Tech University, and Dr. S. A. Kiger of the Research Group, SMD.

COL Tilford C. Creel, CE, was Commander and Director of WES during this study and the preparation and publication of this report. Mr. F. R. Brown was Technical Director.

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
Distribution/	
Availability Codes	
Avail and/or	
Special	

Dist
A1

DO NOT
REPRODUCE

CONTENTS

	<u>Page</u>
PREFACE	1
LIST OF ILLUSTRATIONS AND TABLES	3
CONVERSION FACTORS, NON-SI TO SI (METRIC)	
UNITS OF MEASUREMENT	4
CHAPTER 1 INTRODUCTION	5
CHAPTER 2 ANALYTICAL PROCEDURE	6
2.1 DEFINITIONS OF DUCTILITY AND RESISTANCE	6
2.2 DESCRIPTION OF LOAD	7
2.3 STRUCTURAL IDEALIZATION	8
2.4 NUMERICAL SOLUTION	8
CHAPTER 3 SOLUTIONS	14
3.1 RESPONSE CHARTS	14
3.2 SOLUTION ACCURACY	14
3.3 EXAMPLE PROBLEMS	14
3.4 COMPUTER CODE	17
CHAPTER 4 CONCLUSIONS	29
REFERENCES	30
APPENDIX A COMPUTER CODE LISTING	31
APPENDIX B EXAMPLE COMPUTER SOLUTIONS	51
APPENDIX C NOTATION	61

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
2.1	SDOF analytical model	11
2.2	Speicher-Brode relationships for a 1-MT surface burst weapon	12
2.3	Typical overpressure decay curves for a specific nuclear weapon at various overpressures	13
3.1	Maximum response of an elastic-plastic system subjected to a 10-psi Speicher-Brode pulse	20
3.2	Maximum response of an elastic-plastic system subjected to a 50-psi Speicher-Brode pulse	21
3.3	Maximum response of an elastic-plastic system subjected to a 100-psi Speicher-Brode pulse	22
3.4	Maximum response of an elastic plastic system subjected to a 200-psi Speicher-Brode pulse	23
3.5	Maximum response of an elastic-plastic system subjected to a 500-psi Speicher-Brode pulse	24
3.6	Maximum response of an elastic-plastic system subjected to a 1,000-psi Speicher-Brode pulse	25
3.7	Maximum response of an elastic-plastic system subjected to a 10,000-psi Speicher-Brode pulse	26
3.8	Maximum response of an elastic-plastic system subjected to a 20,000-psi Speicher-Brode pulse	27
3.9	Maximum response of an elastic-plastic system subjected to a 50,000-psi Speicher-Brode pulse	28

LIST OF TABLES

<u>Table</u>		
2.1	Speicher-Brode relationships for a 1-MT surface-burst weapon	10
3.1	Interpolation formulas	19

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimetres
kilofeet	0.3048	kilometres
kilotons (nuclear equivalent of TNT)	4.184	terajoules
pounds (mass)	0.45359237	kilograms
pounds per square inch	6.894757	kilopascals
pounds per square inch per second	6.894757	kilopascals/second
tons (nuclear equivalent of TNT)	4.184	gigajoules

RESPONSE OF AN ELASTIC-PLASTIC STRUCTURE SUBJECTED TO
A SIMULATED NUCLEAR BURST

CHAPTER 1

INTRODUCTION

Very few structures are designed to remain elastic under highly impulsive loads. Systems that are designed to behave elastically under such loads are generally uneconomical and tend to have structural characteristics that attract greater dynamic forces. Consequently, some plastic behavior is desirable for the largest dynamic loads that are anticipated to occur.

The stress distribution in a structure that undergoes a plastic response is complex and difficult to predict. Hence, the design and failure criteria for such structures are generally governed by limitations on response, e.g., deflections and rotations, rather than by limitations on stresses.

This paper presents the mathematical model and the numerical solution for the response of structures that behave as elastic-perfectly plastic systems when subjected to monotonically decaying loads. The loading definition is intended to simulate the pressure-time history of a nuclear pulse with zero rise time and no negative phase.

CHAPTER 2

ANALYTICAL PROCEDURE

2.1 DEFINITIONS OF DUCTILITY AND RESISTANCE

A measure of the total elastic and plastic deformation in a structure is its ductility. In this paper, ductility will be defined as the ratio of the maximum displacement under a prescribed load to peak elastic displacement, i.e., x_m/x_y ¹ in Figure 2.1. The maximum ductility that a structure can sustain without collapse is controlled by its material and geometric characteristics and is an indicator of the amount of energy that can be absorbed prior to failure.

The relationship between static load and deflection, i.e., the resistance function, for many structural elements may be idealized as the elastic-perfectly plastic curve shown in Figure 2.1. For monotonic dynamic loads, it is generally assumed that the resistance function maintains the same characteristic form as for the static situation. However, the magnitudes may be increased to represent the enhanced strength of the material under the high strain rates associated with dynamic loads.

2.2 DESCRIPTION OF LOAD

In the past, nuclear pressure histories have often been represented as simple triangular functions or as superimposed combinations of simple triangles (References 1 and 2). Analyses made with such loading definitions have often proved to be reliable, particularly when the loads are most impulsive or when the duration of the load is large compared to the natural period of the structure. However, when attempting to represent some nuclear weapon loadings, the use of an "equivalent" triangular function introduces significant error. The selection of an appropriate triangle to represent a particular nuclear pulse adds one more degree of uncertainty to the already subjective dynamic analysis.

Analytic approximations to actual nuclear burst overpressures have recently been developed. The most recent expression for the overpressures can

¹For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix C).

be found in Reference 3 with subsequent modifications by memoranda from the authors. The Speicher-Brode fit relates height of burst, range, time of arrival, positive phase duration, and overpressure for a 1-kiloton² (KT) weapon. Calculation of the quantities listed above, as well as positive phase impulse, for a 1 megaton (MT) surface burst weapon are included in Table 2.1 and Figure 2.2. Cube-root scaling can be used to relate the quantities of interest for different weapon yields.

2.3 STRUCTURAL IDEALIZATION

Many structures may be idealized as single-degree-of-freedom (SDOF) spring-mass models in order to determine their fundamental response. More complex structures may be idealized as a combination of spring-mass models that are superimposed by modal superpositioning. The idealized SDOF model used in this paper, as well as the resistance and loading idealizations, are shown in Figure 2.1.

The differential equation of motion for the undamped SDOF model is given below.

$$m\ddot{x} + kx = F(t) \quad (2.1)$$

where

$$\ddot{x} = d^2y/dt^2 = \text{acceleration}$$

and $kx = r_m$, if plastic response has occurred

Viscous damping is generally not included in the analysis of structures that are subjected to short-duration monotonic loads, particularly when only the peak response is of primary interest. Damping at less than 5 or 6 percent of critical will have only a minor effect on peak response for nonoscillating loads.

Equation 2.1 can be nondimensionalized by a transformation of the independent variables to yield the following equations from Reference 2.

$$\frac{1}{4\pi^2} \ddot{\eta} + \eta = \frac{F_1}{r_m} f(\xi), \text{ if elastic,} \quad (2.2)$$

²A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

and

$$\frac{1}{4\pi^2} \ddot{\eta} + 1 = \frac{F_1}{r_m} f(\xi) \text{ , if plastic,} \quad (2.3)$$

where

$$\eta(\xi) = x(t)/x_y$$

$$\ddot{\eta}(\xi) = T^2 \ddot{x}(t)/x_y$$

$$\xi = t/T$$

x_y = displacement at first yield

$$T = 2\pi \sqrt{\frac{m}{k}} = \text{natural period}$$

It should be noted that the specified forcing function in Equations 2.2 and 2.3 implies that pressures may be normalized with respect to a single time parameter. However, the Speicher-Brode loading definition is a function of time and of peak overpressure and may not be normalized by a single parameter as illustrated in Figure 2.3. Thus, a separate response chart must be developed for each value of peak overpressure, P_s .

2.4 NUMERICAL SOLUTION

There are several numerical methods for solving the nondimensionalized equations of motion. A method that is frequently applied to problems in structural dynamics is the Newmark β method (Reference 4). This method was selected for numerical analysis because of its flexibility and established criteria for stability and convergence.

From previously defined relationships, we have

$$x(t) = x_y \eta(\xi)$$

$$\dot{x}(t) = x_y \dot{\eta}(\xi)/T$$

$$\ddot{x}(t) = x_y \ddot{\eta}(\xi)/T^2$$

$$\xi = \frac{t}{T}$$

For our initial conditions

$$\eta_0 = 0$$

$$\dot{\eta}_0 = 0$$

The initial value of the acceleration term is

$$\ddot{\eta}_0 = 4\pi^2 F_1 / r_m$$

The Newmark β equations may be written in nondimensionalized form as indicated below:

$$\eta_{i+1} = \eta_i + \left(\frac{\Delta t}{T}\right) \dot{\eta}_i + (1/2 - \beta) \left(\frac{\Delta t}{T}\right)^2 \ddot{\eta}_i + \beta \left(\frac{\Delta t}{T}\right)^2 \ddot{\eta}_{i+1} \quad (2.5)$$

$$\dot{\eta}_{i+1} = \dot{\eta}_i + 1/2 \left(\frac{\Delta t}{T}\right) (\ddot{\eta}_i + \ddot{\eta}_{i+1}) \quad (2.6)$$

By making an assumption for the acceleration at the $(i+1)$ time step, approximations of the corresponding displacement and velocity terms can be made with the equations above. The resulting displacement can then be inserted into the original differential equation and tested for convergence. The process may be repeated iteratively until convergence is met within a prescribed tolerance.

Criteria for selecting an appropriate normalized time increment $(\Delta t/T)$ should not be based solely upon the value of β , i.e., the implied assumption of acceleration between time steps, but should also depend upon the duration of the load. Sufficiently small time steps must be used to provide an appropriate description of the loading function.

As an example of the numerical parameters which might be used: for linear acceleration, $\beta = 1/6$; the normalized time increment limit for convergence = 0.389; and the normalized time increment limit for stability = 0.551 (Reference 4). Also, the time increment typically should not exceed about 1/10 of the duration of the load.

Table 2.1. Speicher-Brode relationships for a
1-MT surface burst weapon.

PSO - Surface overpressure (psi)

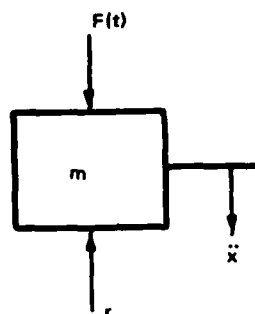
R - Range (kft)

t_a - Time of arrival (ms)

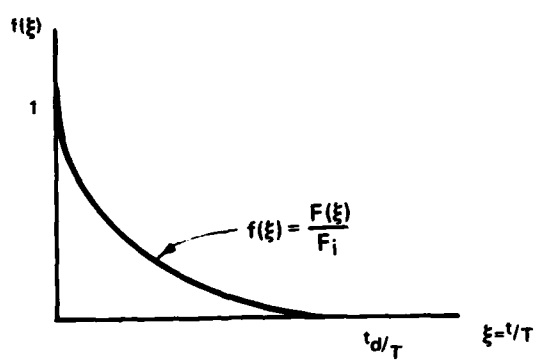
t_d - Positive phase duration (ms)

I_p - Positive phase impulse (psi-ms)

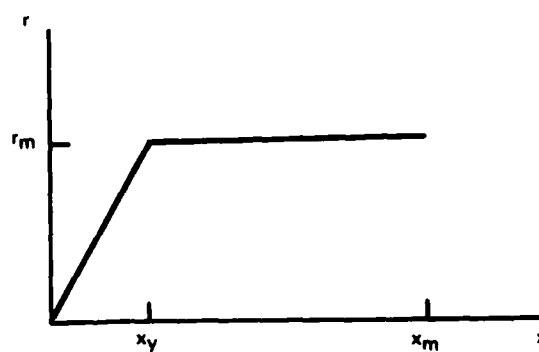
PSO	R	t_a	t_d	I_p
1.0	46.767	34,939.3	4,376.8	1,955
2.0	28.025	18,646.6	3,930.7	3,285
3.0	21.122	12,797.8	3,583.2	4,301
4.0	17.505	9,817.7	3,308.3	5,136
5.0	15.248	8,009.4	3,085.3	5,852
6.0	13.685	6,790.6	2,900.1	6,482
7.0	12.527	5,910.1	2,743.4	7,043
8.0	11.627	5,242.1	2,608.7	7,548
9.0	10.903	4,717.0	2,491.5	8,004
10.0	10.304	4,292.4	2,388.5	8,415
20.0	7.264	2,310.1	1,785.3	10,596
30.0	6.009	1,609.0	1,519.1	11,366
40.0	5.282	1,245.9	1,378.0	12,741
50.0	4.794	1,022.5	1,297.1	14,598
60.0	4.437	870.6	1,249.3	16,469
70.0	4.161	760.2	1,221.5	17,986
80.0	3.939	676.2	1,206.2	18,969
90.0	3.755	610.0	1,199.1	19,482
100.0	3.600	556.4	1,197.5	19,743
200.0	2.752	305.0	1,274.3	28,198
300.0	2.366	215.1	1,357.8	35,047
400.0	2.131	167.9	1,418.5	38,823
500.0	1.967	138.6	1,461.9	42,076
600.0	1.844	118.4	1,493.2	45,206
700.0	1.746	103.7	1,516.2	48,225
800.0	1.666	92.4	1,533.3	51,112
900.0	1.599	83.4	1,546.0	53,856
1,000.0	1.541	76.1	1,555.5	56,460
2,000.0	1.214	41.5	1,575.7	76,529
3,000.0	1.058	28.9	1,557.8	90,071
4,000.0	0.960	22.3	1,535.2	100,208
5,000.0	0.891	18.3	1,513.2	108,274
6,000.0	0.838	15.5	1,493.1	114,954
7,000.0	0.796	13.4	1,474.9	120,646
8,000.0	0.761	11.9	1,458.4	125,602
9,000.0	0.732	10.7	1,443.4	129,994
10,000.0	0.707	9.7	1,429.7	133,940



IDEALIZED MODEL



FORCING FUNCTION



RESISTANCE FUNCTION

Figure 2.1. SDOF analytical model.

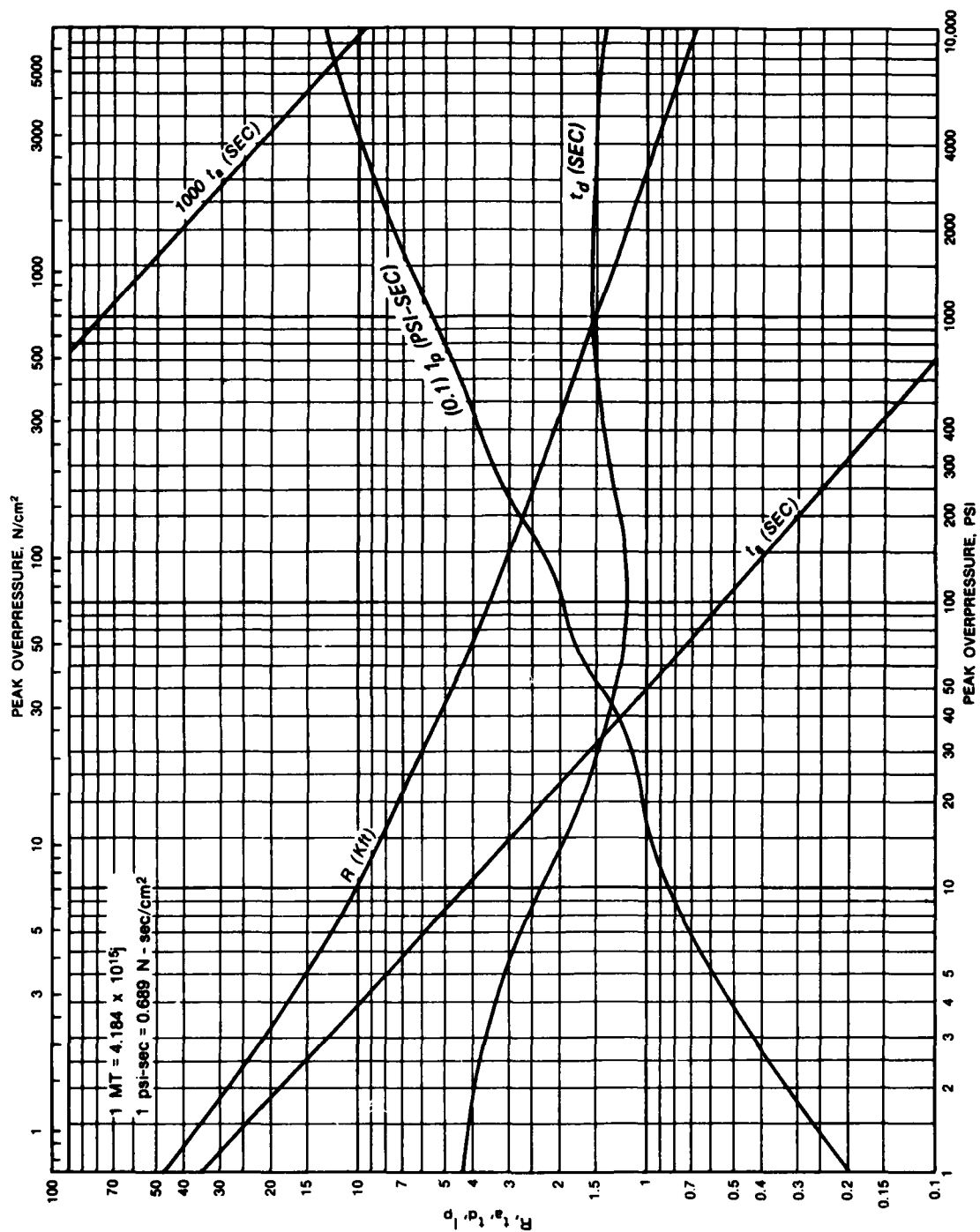
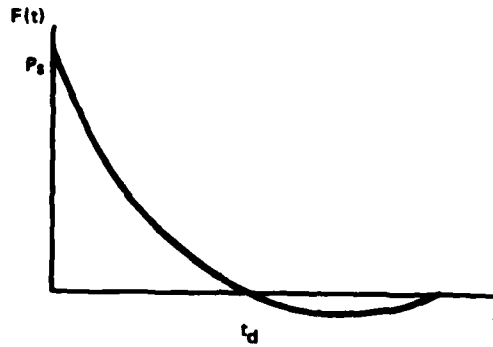
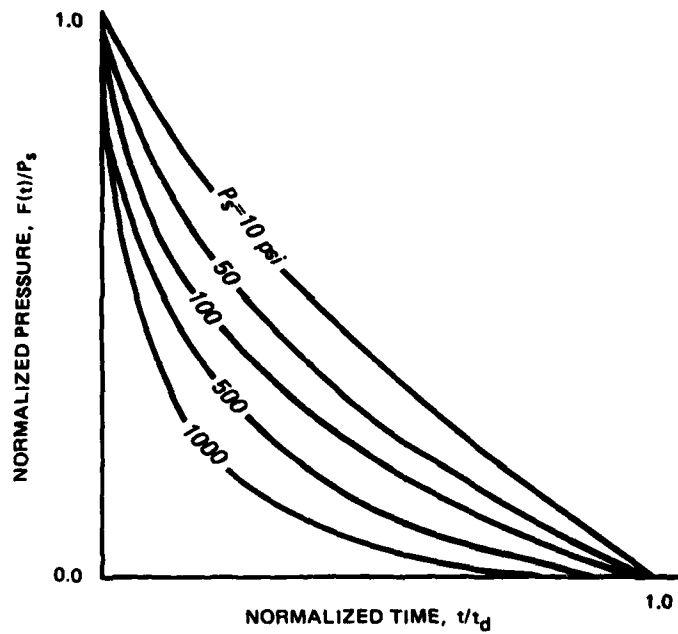


Figure 2.2. Speicher-Brode relationships for a 1-MT surface burst weapon.



a. Nuclear overpressure decay curve.



b. Normalized pressure history.

Figure 2.3. Typical overpressure decay curves for a specific nuclear weapon at various overpressures.

CHAPTER 3

SOLUTIONS

3.1 RESPONSE CHARTS

Once the differential equations have been nondimensionalized, the solutions can be plotted over specific ranges of the nondimensionalized parameters to produce a practical design tool. Normalized response charts for triangular loads (Reference 2) and bilinear loads (Reference 5) are available in the open literature.

Charted solutions for the Speicher-Brode overpressure description are provided in Figures 3.1-3.9. It should be repeated that because the normalized pressure history definition is a function of two independent variables, i.e., time and peak overpressure, a unique solution to the differential equation cannot be obtained. However, uniqueness was obtained in this case by holding the peak overpressure constant, thereby creating an equation with a single independent variable. As a result, separate charts were plotted for each peak overpressure.

3.2 SOLUTION ACCURACY

Response charts are provided for peak overpressures ranging from 10 psi to 50,000 psi. For design purposes, reasonable accuracy may be obtained at intermediate overpressures by interpolating between the given charts. If more accurate solutions are desired, a computer code is provided in Appendix A that will give numerically accurate solutions for any desired overpressure.

A comparison of solutions obtained from the response charts with solutions obtained from the computer code has indicated that logarithmic interpolation formulas will in general provide more accurate solutions between respective charts. Although linear interpolation between any of the charts will provide reasonable answers, more accurate solutions can sometimes be obtained with logarithmic interpolation formulas. Appropriate interpolation formulas are presented in Table 3.1.

3.3 EXAMPLE PROBLEMS

The number of ways that the response charts may be used are too numerous to sufficiently describe here. In addition to the fact that the user may

enter the charts with several different combinations of input parameters, there are many different ways to arrive at those parameters themselves, e.g., natural period, yield deflection, and maximum resistance. Hence, the following examples are only provided to illustrate the actual mechanics of using the charts. It is assumed that the user will know how to compute the basic properties of the physical model.

In this example, the maximum response is determined for a system with a natural period of 0.300 seconds, a maximum resistance of 10 psi, and a peak elastic deflection of 0.5 inch. The structure is subjected to a 20-KT surface burst weapon at 25 psi.

In the response curves, the natural period of the structure has been normalized with respect to the positive phase duration of the load. To find the positive phase duration for the prescribed loading, see Figure 2.2 ($t_d = 1.6$ seconds).

By cube-root scaling, the duration of a 20-KT weapon is computed as

$$\frac{t_d}{1.6 \text{ s}} = \left(\frac{20 \text{ KT}}{1,000 \text{ KT}} \right)^{1/3}$$

$$t_d = 0.434 \text{ s}$$

Computing the response chart input parameters

$$\frac{t_d}{T} = \frac{0.434}{0.300} = 1.45$$

$$\frac{P_s}{r_m} = \frac{25}{10} = 2.50$$

Now, entering the 10-psi response chart (Figure 3.1)

$$\mu_{10} = \frac{x_m}{x_y} = 16$$

and, entering the 50-psi response chart (Figure 3.2)

$$\mu_{50} = 6.5$$

Interpolating (Table 3.1)

$$\mu_{25} = \exp \left[\frac{\ln \left(\frac{25}{50} \right)}{\ln \left(\frac{10}{50} \right)} \cdot \ln \left(\frac{16}{6.5} \right) + \ln(6.5) \right] = 9.58$$

The predicted maximum response is

$$x_m = \mu_{25} x_y = 9.58 (0.5 \text{ inch}) = 4.79 \text{ inches}$$

Similarly, the estimated time to maximum response is

$$t_m = 0.38 \text{ second}$$

The maximum response as determined directly by computer analysis is indicated in Appendix B. In this case, there is an interpolation error of approximately 2 percent. Using a linear interpolation, the maximum response would be predicted as $\mu = 12.4$, which is an error of approximately 32 percent.

In a second example, consider a system with a natural period of 0.50 second and a maximum resistance of 50 psi. Using a 75-KT weapon, the peak overpressure for which the structure can maintain a ductility of 15 may be obtained by the following procedure.

Assume a peak overpressure of 100 psi. From Table 2.1, the positive phase duration for a 1-MT weapon is 1.198 seconds. For a 75-KT weapon, the duration is scaled as follows:

$$\frac{t_d}{1.198 \text{ s}} = \left(\frac{75 \text{ KT}}{1,000 \text{ KT}} \right)^{1/3}$$

$$t_d = 0.505 \text{ s}$$

Now, computing the nondimensionalized parameters based on the assumed overpressure

$$\frac{t_d}{T} = \frac{0.505}{0.050} = 10.1$$

$$\frac{P_s}{r_m} = \frac{100}{50} = 2.0$$

Using the 100-psi response chart, a ductility of 28 is read. That is higher than our limiting ductility. Therefore, try a lower peak overpressure of 50 psi (Figure 3.2). The positive phase duration of 1.297 seconds for a 1-MT weapon at 50 psi scales to 0.547 second for a 75-KT weapon.

The new input parameters are

$$\frac{t_d}{T} = \frac{0.547}{0.050} = 10.9$$

$$\frac{P_s}{r_m} = \frac{50}{50} = 1.0$$

From the 50-psi response chart (Figure 3.2), a much lower ductility of 3.2 is read. Finally, interpolating between the 50- and 100-psi values (Table 3.1)

$$P_s = \frac{(15 - 3.2)}{(28 - 3.2)} \cdot (100 - 50) + 50$$

$$P_s = 74 \text{ psi}$$

The correct solution was determined by computer analysis to be approximately 77 psi. The interpolation error is approximately 4 percent.

3.4 COMPUTER CODE

The code provided in Appendix A was written in Fortran for the Tektronix 4081. It is an interactive code that has been modularized to minimize memory requirements. The code should be easily adaptable to other machines with modification or elimination of the plot routines and overlay structure. The user should also find it quite simple to add alternate loading definitions to the code, if so desired.

Upon initialization of the program, a list of the available user options is displayed to the screen. These options and a brief description of each follow. A sample session is included in Appendix B.

- X - EXIT PROGRAM - The user may exit the program any time there is a request to SELECT OPTION.

- A - ANALYZE - The Newmark β analysis is performed and results are displayed. A complete response history including normalized displacements, velocities, and accelerations may be optionally displayed.
- D - DISPLAY DATA - All numerical parameters, the current loading description, and structural parameters are displayed to the screen.
- H - HELP - A list of the available options is provided upon request.
- I - INITIAL PASS - This option assists the new user in making a first run through the program. The experienced user may find it to be a beneficial option when no modifications in the numerical parameters are required prior to analysis.
- L - LOADING FUNCTION - The user may select a Speicher-Brode or triangular loading description. The weapon, peak overpressure, and height of burst are requested if the Speicher-Brode description is selected. Peak overpressure and duration are requested for the triangular function.
- N - NUMERICAL PARAMETERS - Certain numerical parameters may be changed by the user. The values of Beta, the integration increment, the convergence tolerance, and the number of pressure stations to be computed may be changed by selecting this option. Default values are displayed.
- O - OUTPUT DEVICE - When large quantities of data are to be output, the user may select for that data to be routed to the printer.
- P - PLOT - Normalized displacements, velocities, accelerations, and a description of the loading function may be displayed in graphical form upon request.
- S - SET VALUES FOR ANALYSIS - The natural period of the structure and its peak resistance are requested by this option.
- T - TITLE - Output data and plots display a title that may be changed by selecting this option.

Table 3.1. Interpolation formulas.

Type of Interpolation	To Find	Formula	Suggested Ranges (psi)
Linear	μ	$\mu_{P_s} = \frac{(P_s - P_{s1})}{(P_{s2} - P_{s1})} \cdot (\mu_2 - \mu_1) + \mu_1$	50-100
	P_s	$P_s = \frac{(\mu_{P_s} - \mu_1)}{(\mu_2 - \mu_1)} \cdot (P_{s2} - P_{s1}) + P_{s1}$	
Natural logarithmic	μ	$\mu_{P_s} = \exp \left[\frac{\ln \left(\frac{P_s}{P_{s2}} \right)}{\ln \left(\frac{P_{s1}}{P_{s2}} \right)} \cdot \ln \left(\frac{\mu_1}{\mu_2} \right) + \ln(\mu_2) \right]$	10-50
			100-200
			200-500
			500-1,000
			1,000-10,000
	P_s	$P_s = \exp \left[\frac{\ln \left(\frac{\mu_{P_s}}{\mu_2} \right)}{\ln \left(\frac{\mu_1}{\mu_2} \right)} \cdot \ln \left(\frac{P_{s1}}{P_{s2}} \right) + \ln(P_{s2}) \right]$	10,000-20,000
			20,000-50,000

Notation: P_s - overpressure for which solution is desired
 P_{s1} - overpressure of response chart before P_s
 P_{s2} - overpressure of response chart after P_s
 μ_{ps} - ductility at desired overpressure
 μ_1 - ductility from response chart before P_s
 μ_2 - ductility from response chart after P_s

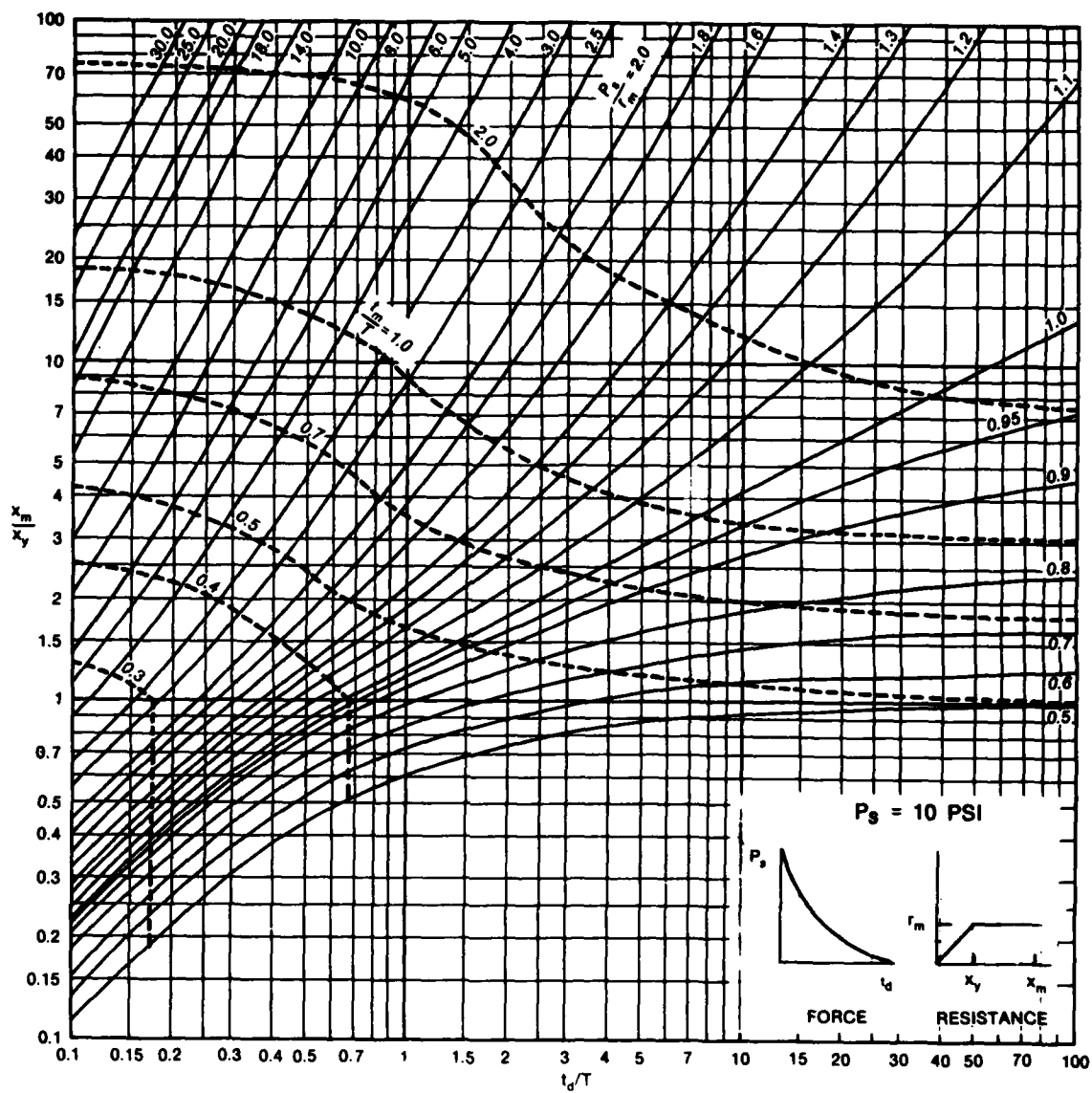


Figure 3.1. Maximum response of an elastic-plastic system subjected to a 10-psi Speicher-Brode pulse.

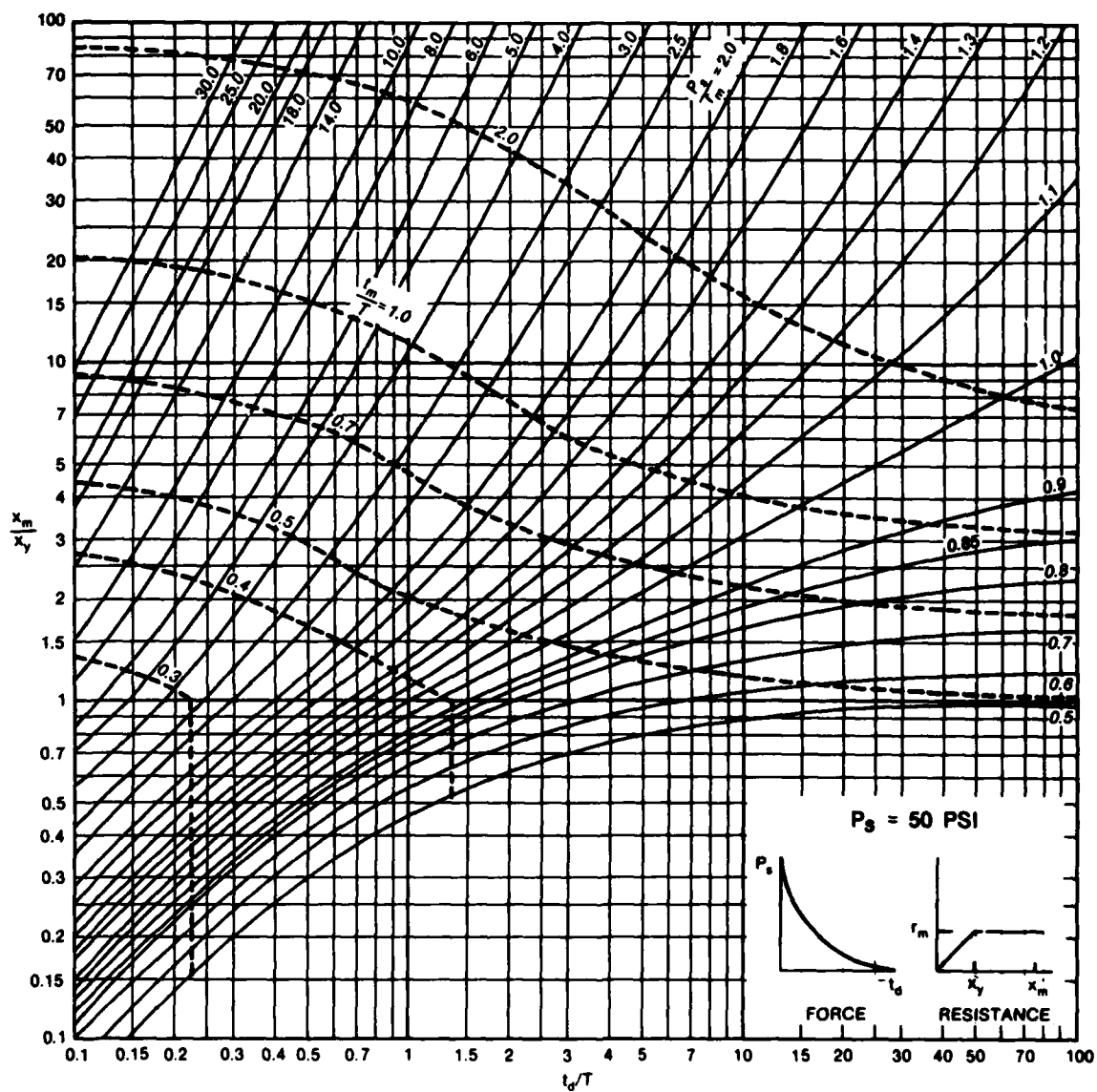


Figure 3.2. Maximum response of an elastic-plastic system subjected to a 50-psi Speicher-Brode pulse.

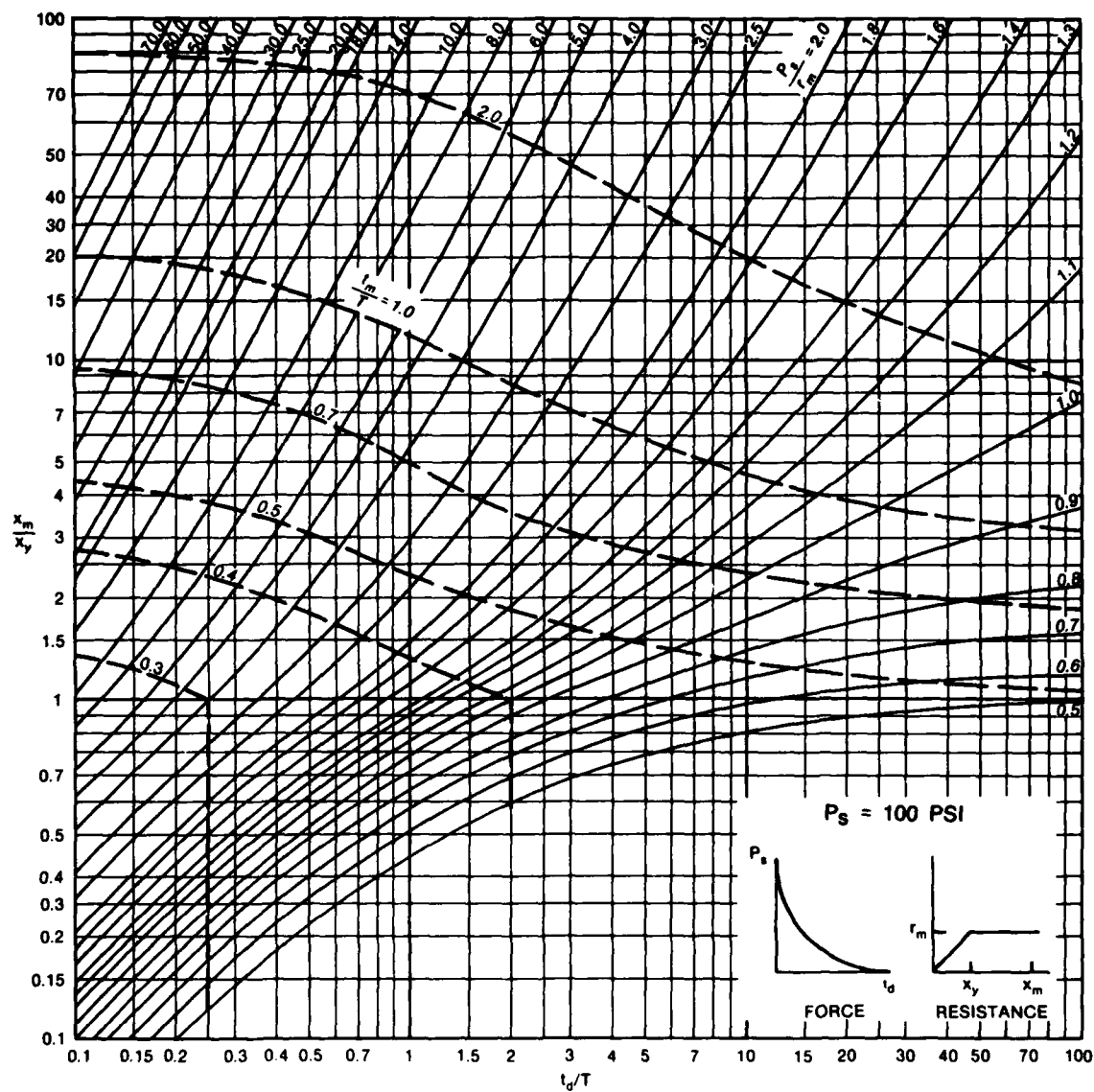


Figure 3.3. Maximum response of an elastic-plastic system subjected to a 100-psi Speicher-Brode pulse.

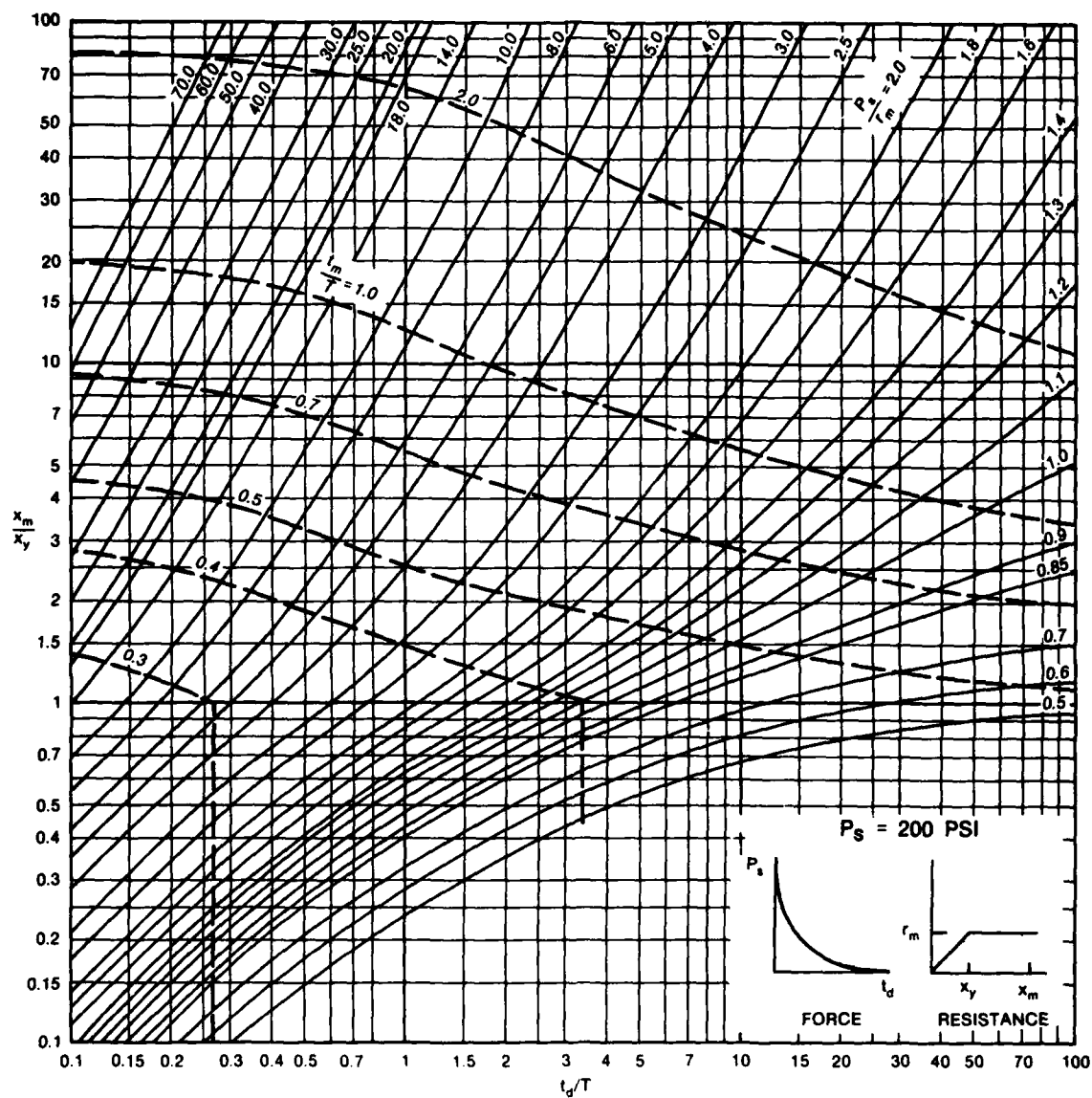


Figure 3.4. Maximum response of an elastic-plastic system subjected to a 200-psi Speicher-Brode pulse.

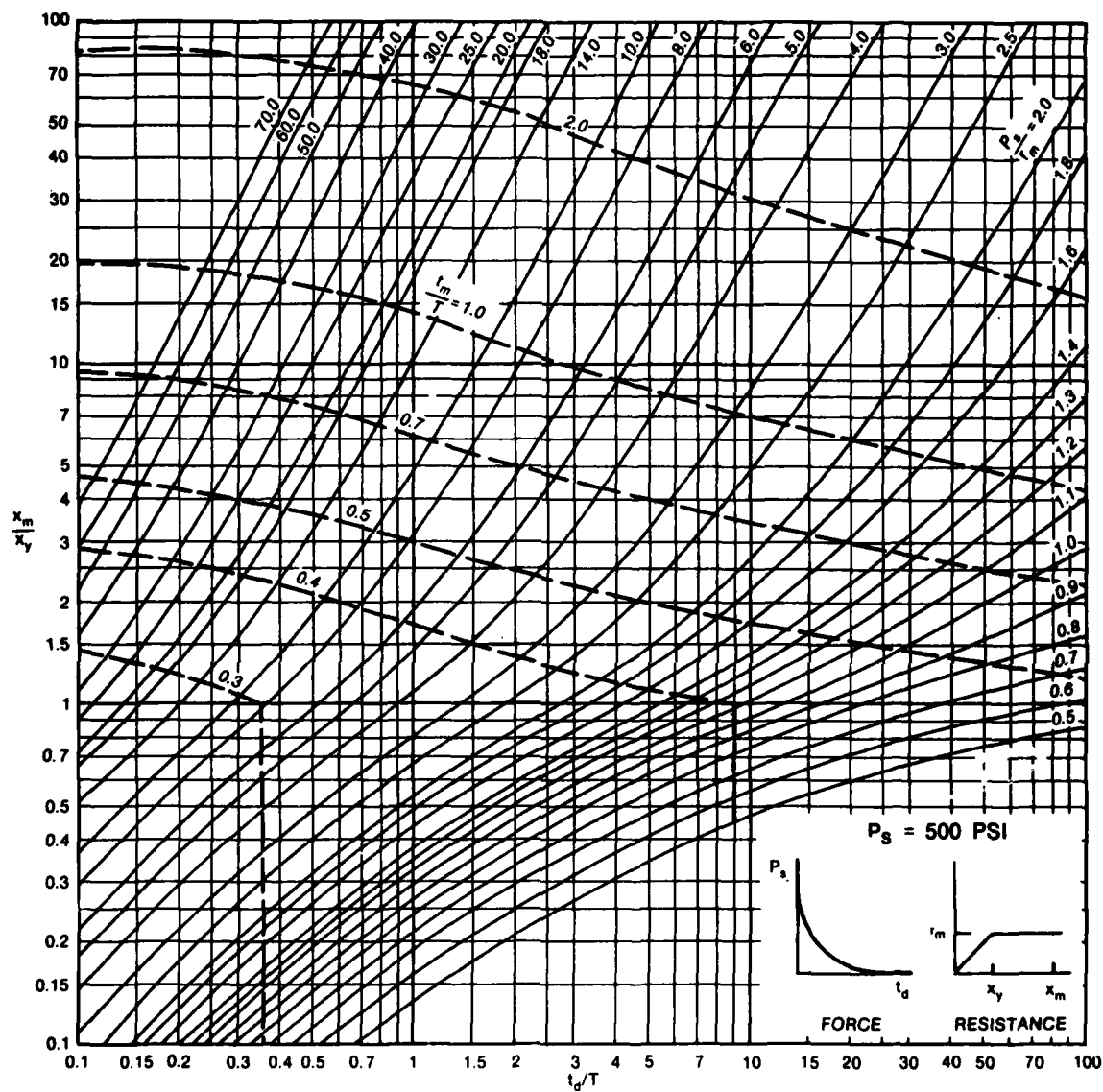


Figure 3.5. Maximum response of an elastic-plastic system subjected to a 500-psi Speicher-Brode pulse.

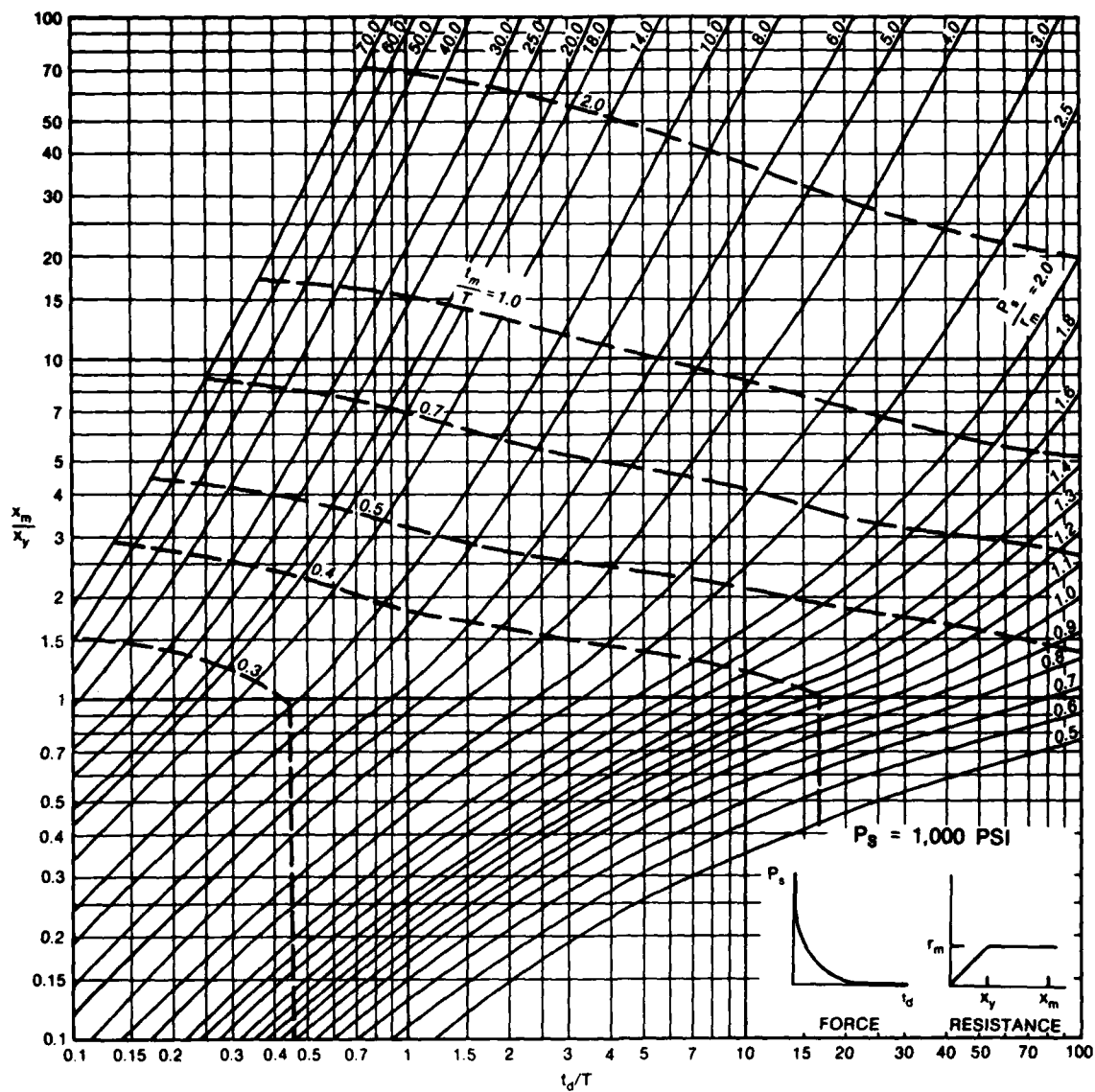


Figure 3.6. Maximum response of an elastic-plastic system subjected to a 1,000-psi Speicher-Brode pulse.

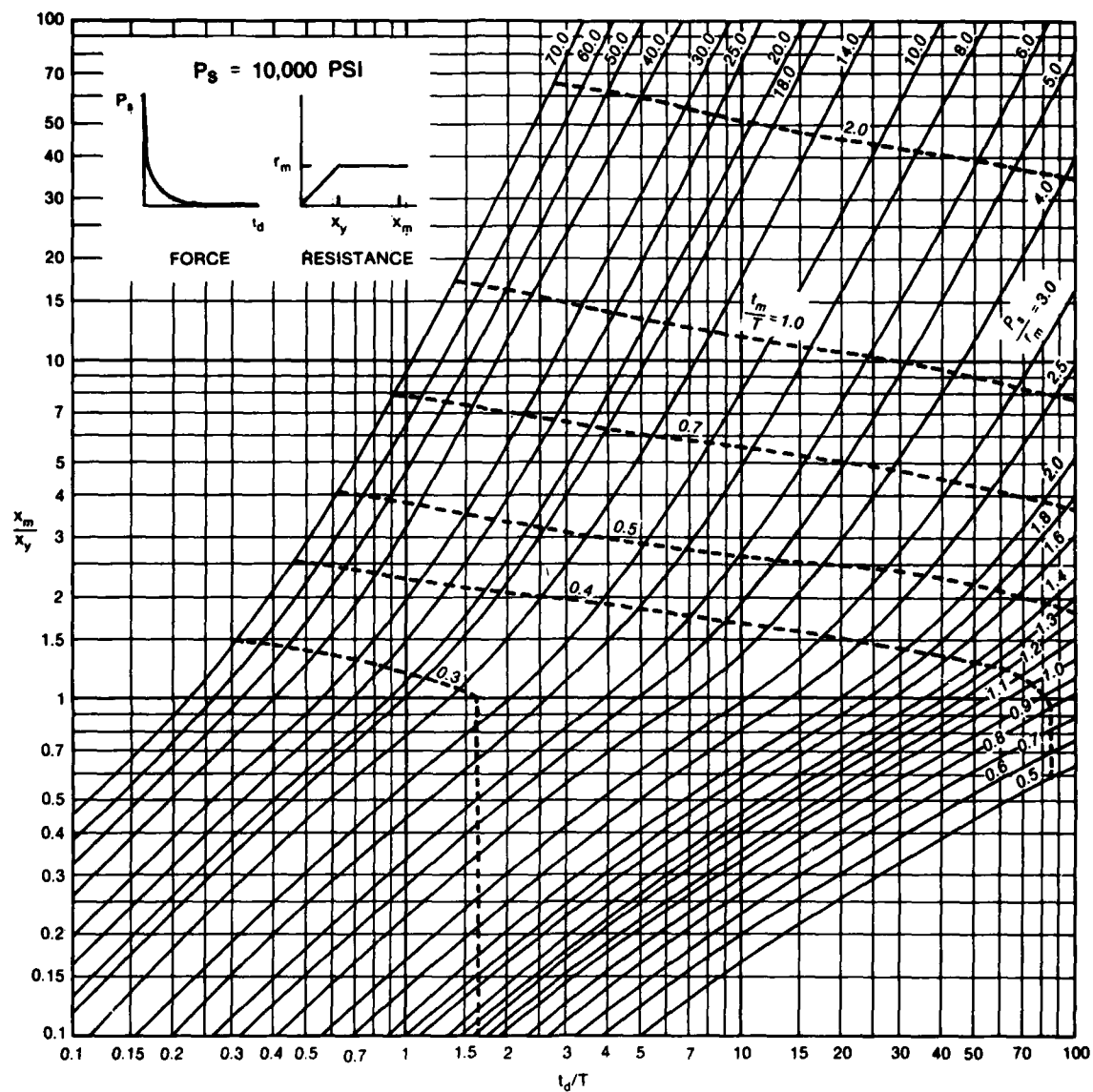


Figure 3.7. Maximum response of an elastic-plastic system subjected to a 10,000-psi Speicher-Brode pulse.

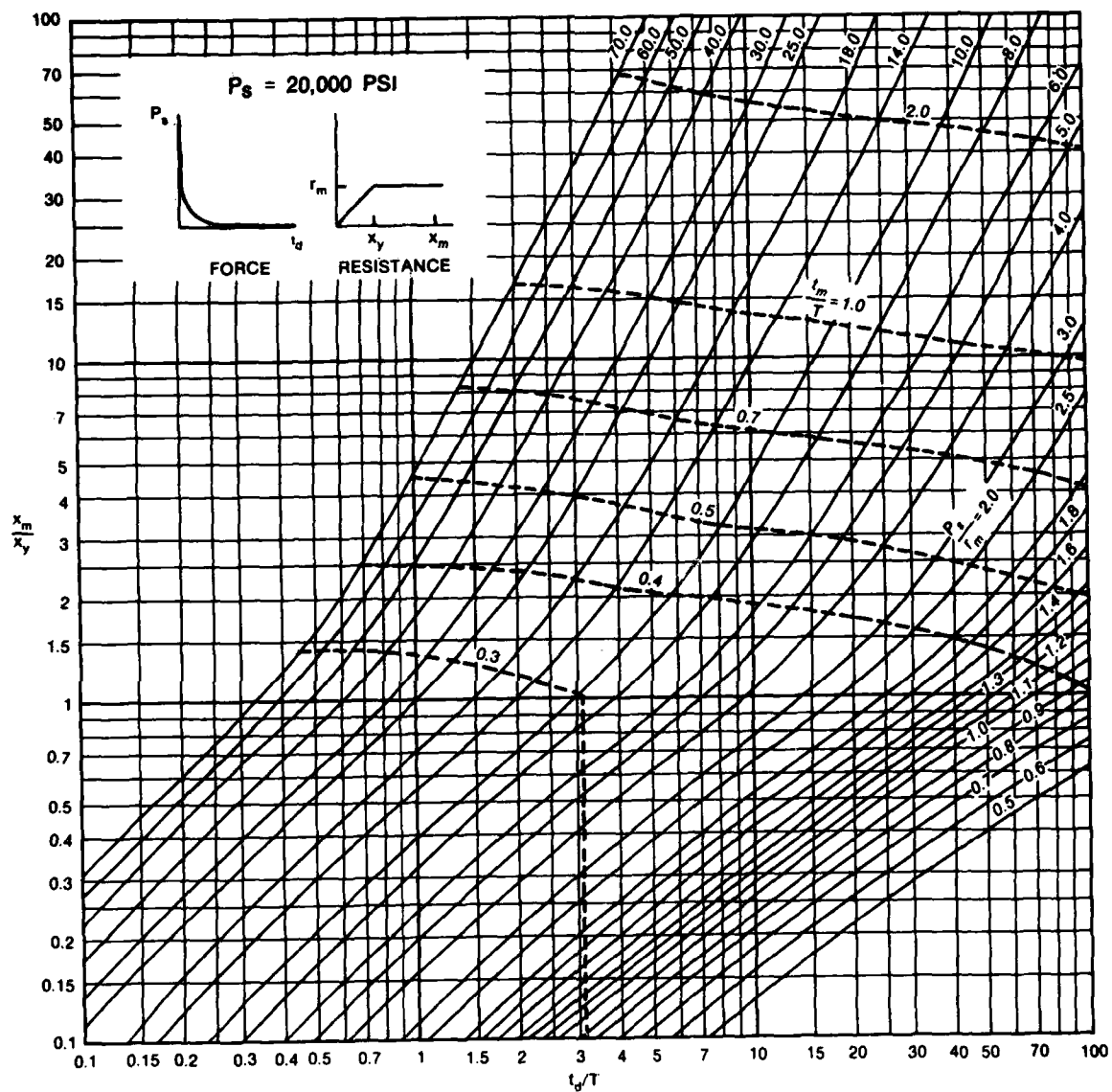


Figure 3.8. Maximum response of an elastic-plastic system subjected to a 20,000-psi Speicher-Brode pulse.

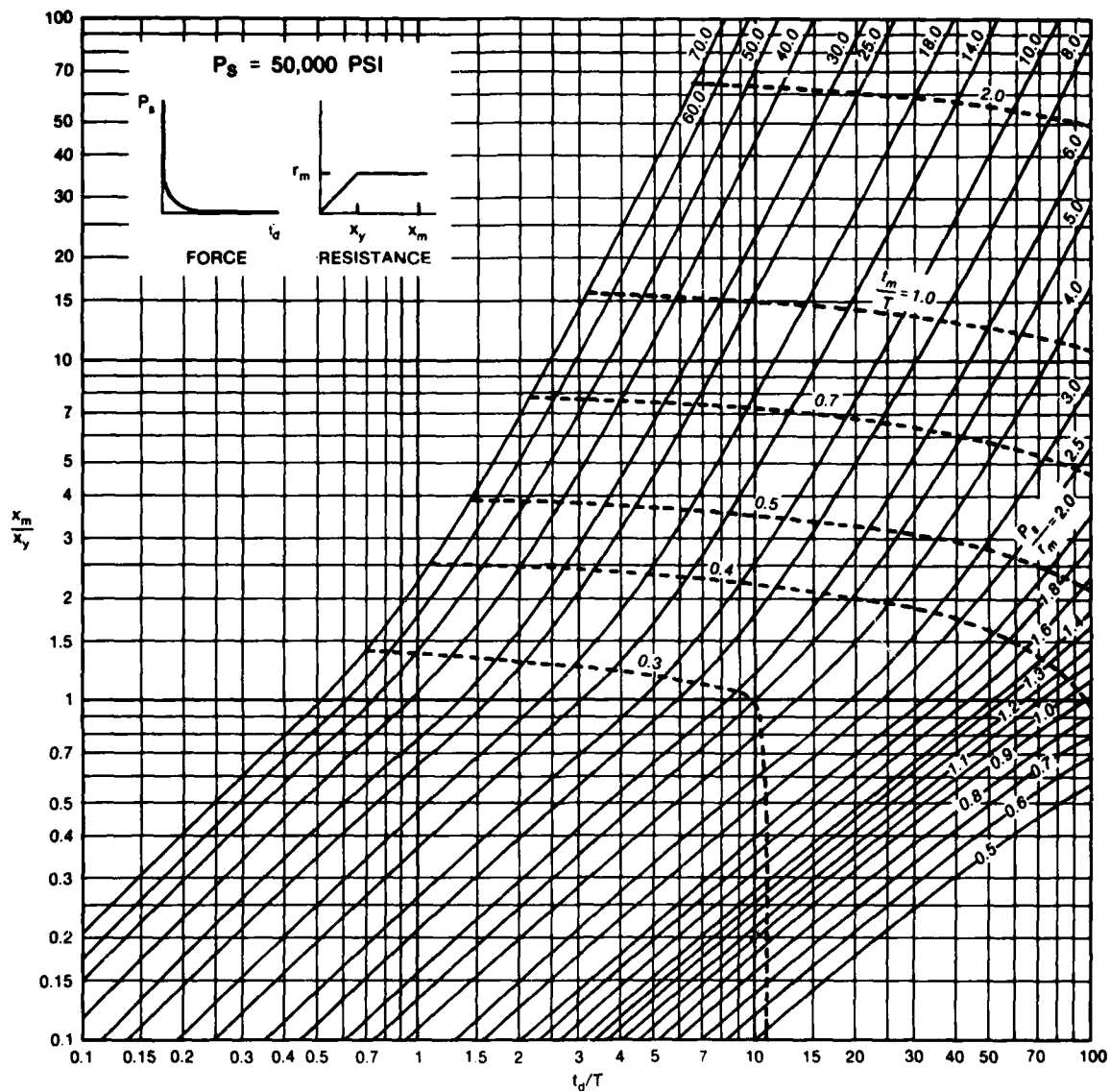


Figure 3.9. Maximum response of an elastic-plastic system subjected to a 50,000-psi Speicher-Brode pulse.

CHAPTER 4

CONCLUSIONS

The analysis and design of structures to resist loadings from nuclear weapons involve many parameters that are difficult to define. However, if those unknowns can be determined or at least approximated, then a straightforward solution can be readily obtained.

Two different ways for arriving at that solution for elastic-plastic systems with simulated nuclear loading definitions have been provided in this paper. The computer solution offers a quick and accurate way to investigate the effects of different parameters on the response. However, if a computer is not readily available or if a rough approximation to the numerically accurate solution is adequate, then the response charts are most beneficial. The response charts provide an efficient method for preliminary design calculations and for parametric investigations into such things as the effect of peak overpressure, weapon yield, structural resistance, and structural stiffness on the maximum response of a structure.

The charts do provide numerically accurate solutions for the specified overpressures, but interpolation to those overpressures not included on a chart does introduce some error into the analysis.

REFERENCES

1. American Society of Civil Engineers; "Design of Structures to Resist Nuclear Weapons Effects"; Manuals of Engineering Practice No. 42, 1961; New York.
2. J. M. Biggs; "Introduction to Structural Dynamics"; 1964; McGraw-Hill, New York.
3. S. J. Speicher and H. L. Brode; "Airblast Overpressure Analytical Expression for Burst Heights, Range and Time--Over an Ideal Surface"; PSR Note 385, November 1981; Pacific Sierra Research, Santa Monica, California.
4. N. M. Newmark; "A Method of Computation for Structural Dynamics"; Transactions, American Society of Civil Engineers, 1962, Vol. 127, Part 1, Pages 1406-1435; New York.
5. J. S. Hopkins; "Charts for Predicting Response of a Simple Spring-Mass System to Bilinear Blast Loads"; Report No. TN-1669, June 1983; Naval Civil Engineering Laboratory, Port Hueneme, California.

APPENDIX A
COMPUTER CODE LISTING

```

C*****
C  PROGRAM FOR DETERMINING THE NORMALIZED RESPONSE OF AN SDOF      *
C  ELASTIC-PLASTIC MODEL SUBJECTED TO A SPEICHER-BRODE OR        *
C  A TRIANGULAR PULSE.  RESPONSES ARE NORMALIZED BY THE ELASTIC  *
C  DEFLECTION.          LES GUICE          AUGUST 1983          *
C*****
      IMPLICIT INTEGER*2(I-N,*)
      INTEGER*1 TITLE(72)
      DIMENSION P(250),RNU(501),RNUD(501),RNUDD(501)
      DATA TITLE/' ',' ','N','O','R','M','A','L','I','Z','E','D','
1     ' ','R','E','S','P','O','N','S','E',' ','O','F',' ','A','
2     ' ','S','D','O','F',' ','E','L','A','S','T','I','C',' ','-','
3     'P','L','A','S','T','I','C',' ','M','O','D','E','L',' ','
4     ' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ','
5     ' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' ',' '
      NOPT=11
C
C  INITIALIZE ALL VALUES
C
      CALL GRSTRT(9)
      CALL BFACT(0,'USR:ANLOLY.LIB ')
1     LUO=6
      JOP=4
      IPASS=0
      NSTP=501
      NST=500
      NT=250
      NP=250
      W=1000.0
      PKT=100.0
      HOBK=0.0
      BT=0.16667
      TOL=1.0E-3
      TI1=0.01
      TI2=0.01
      TN=1.0
      RMX=1.0
10    CALL OVLINK('HELPOP ',LUO)
C
98    CALL OVLINK('GETOPT ',NOPT,JOP)
      GO TO(99999,1000,2000,10,3000,3000,4000,5000,6000,
1     7000,8000),JOP
C
C  ANALYZE BY NEWMARK BETA METHOD
C
1000  CALL OVLINK('NEWMRK ',LUO,P,NT,NP,RNU,RNUD,RNUDD,NSTP,NST,
1     TD,TN,TI1,TI2,PKT,RMX,BT,TOL,NUU,TINC)
      IPASS=2
      GO TO 98
C
C  DISPLAY DATA
C
2000  CALL OVLINK('DISPOP ',LUO,JOP,LFUNC,W,PKT,TD,TA,R,HOBK,TN,RMX,

```

```

      1 DPT,P,NT,NP,PKT,TITLE,BT,TI1,TI2,TOL,NP)
      IF(JOP.EQ.5)GO TO 7000
      GO TO 98
C
C   LOADING FUNCTION
C
3000  CALL OVLINK('LOADOP ',LUO,JOP,LFUNC,W,PKT,TD,TA,R,HOBK,DPT,
      1 P,NT,NP)
      IPASS=1
      IF(JOP.EQ.5)GO TO 2000
      GO TO 98
C
C   NUMERICAL PARAMETERS
C
4000  CALL OVLINK('NUMOP ',LUO,BT,TI1,TI2,TOL,NP)
      GO TO 98
C
C   OUTPUT DEVICE
C
5000  CALL OVLINK('OUTOP ',LUO)
      GO TO 98
C
C   PLOT RESULTS
C
6000  CALL OVLINK('PLOTOP ',LUO,TITLE,RNU,RNUD,RNUDD,NSTP,
      1 P,NT,NP,TD,NNU,TINC,IPASS)
      GO TO 98
C
C   SET VALUES FOR ANALYSIS
C
7000  CALL OVLINK('SETOP ',LUO,TN,RMX)
      IF(JOP.EQ.5)GO TO 1000
      GO TO 98
C
C   TITLE
C
8000  CALL OVLINK('TITLOP ',TITLE)
      GO TO 98
C
C   EXIT PROGRAM
C
99999 STOP
      END

```

```

SUBROUTINE HELPOP(LUO)
IMPLICIT INTEGER*2(I-N,*)
CALL VTSCA(3)
CALL HIBRN8(1)
10 WRITE(LUO,*) '
WRITE(LUO,*) ' NORMALIZED RESPONSE OF AN SDOF ELASTIC-',
1 ' PLASTIC MODEL'
WRITE(LUO,*) '
WRITE(LUO,*) ' NOTE: DEFAULT UNITS ARE INCHES, POUNDS, AND SEC'
WRITE(LUO,*) ' UNLESS OTHERWISE SPECIFIED.'
WRITE(LUO,*) '
WRITE(LUO,*) ' AVAILABLE OPTIONS:
WRITE(LUO,*) ' X - EXIT PROGRAM'
WRITE(LUO,*) ' A - ANALYZE'
WRITE(LUO,*) ' D - DISPLAY DATA'
WRITE(LUO,*) ' H - HELP'
WRITE(LUO,*) ' I - INITIAL PASS'
WRITE(LUO,*) ' L - LOADING FUNCTION'
WRITE(LUO,*) ' N - NUMERICAL PARAMETERS'
WRITE(LUO,*) ' O - OUTPUT DEVICE'
WRITE(LUO,*) ' P - PLOT'
WRITE(LUO,*) ' S - SET VALUES FOR ANALYSIS'
WRITE(LUO,*) ' T - TITLE'
WRITE(LUO,*) '
RETURN
END

```

```

SUBROUTINE GETOPT(NOPT,JOP)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*2 JOPT(11)
DATA JOPT/'X ','A ','D ','H ','I ','L ','N ','O ','P ','
1 'S ','T '/
WRITE(6,*) ' SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)'
CALL READC(IOPT,0,0)
WRITE(6,*) '
DO 100 I=1,NOPT
100 IF(IOPT.EQ.JOPT(I))JOP=I
RETURN
END

```

```

C      SUBROUTINE NEWMRK(LUD,P,NT,NP,RNU,RNUD,RNUDD,NSTP,NST,
1      TD,TN,TI1,TI2,PKT,RMX,BT,TOL,NUU,TINC)
C
C      THIS SUBROUTINE IS USED TO INTEGRATE THE SDOF EQUATIONS
C      OF MOTION BY THE NEWMARK-BETA METHOD
C
C      IMPLICIT INTEGER*2(I-N,*)
C      DIMENSION P(NT),RNU(NSTP),RNUD(NSTP),RNUDD(NSTP)
C      DATA INO/'N '//
C      PI=3.1415927
C      ANUM=4.0*PI**2.0
C      COMPUTE MAXIMUM RESPONSE FOR THE RATIO OF TD/TN AND PKT/RMX
C      POR=PKT/RMX
C      DETERMINE TIME INCREMENT TO SATISFY CONVERGENCE AND
C      PROPER DESCRIPTION OF LOADING FUNCTION
C      TI=TI1
C      TINC=TI*TN
C      IF(TD.GT.TN)GO TO 1000
C      TI=TI2
C      TINC=TI*TD
C      SET INITIAL VALUES OF NORMALIZED DISPLACEMENT(RNU),
C      VELOCITY(RNUD), AND COMPUTE INITIAL ACCELERATION(RNUDD)
1000  RNU(1)=0.0
C      RNUMX=RNU(1)
C      TMXT=0.0
C      RNUD(1)=0.0
C      RNUDD(1)=ANUM*POR
C      TIDTN=TINC/TN
C      PERFORM THE INTEGRATION ITERATIVELY
C      BY ASSUMING AN ACCELERATION AND CHECKING CONVERGENCE
C
C      DO 1500 J=1,NST
C      JJ=J+1
C      RNUDD(JJ)=RNUDD(J)
C      DETERMINE THE NORMALIZED PRESSURE THIS TIME STEP
C      CALL PRESS(P,NT,NP,TD,JJ,TINC,SI,FT)
C      COMPUTE NORMALIZED DISPLACEMENT AND VELOCITY
1100  RNU(JJ)=RNU(J)+TIDTN*RNUD(J)+TIDTN*TIDTN*(0.5-BT)*RNUDD(J)+
1      TIDTN*TIDTN*BT*RNUDD(JJ)
C      RNUD(JJ)=RNUD(J)+0.5*TIDTN*(RNUDD(J)+RNUDD(JJ))
C      TNU=RNU(JJ)
C      DETERMINE IF RESPONSE IS IN PLASTIC RANGE
C      IF(RNU(JJ).GT.1.0)TNU=1.0
C      CHECK CONVERGENCE
C      RNUCK=ANUM*(FT*POR-TNU)
C      IF(ABS(RNUCK-RNUDD(JJ)).LE.TOL)GO TO 1200
C      IF(RNUCK.EQ.RNUDD(J))GO TO 1200
C      NOT CONVERGED, ASSUME NEW ACCELERATION
C      RNUDD(JJ)=RNUCK
C      GO TO 1100
C      CONVERGED, DETERMINE IF A MAXIMUM

```

```

1200 IF(RNU(JJ).LE.RNU(J))GO TO 2000
      RNUMX=RNU(JJ)
      TM=SI
      FM=FT
      NNU=JJ
1500 CONTINUE
      WRITE(LUO,*)' CAUTION: SOLUTION NOT CONVERGED!'
C
C DISPLACEMENT IS DECREASING, MAX. AT PREVIOUS STEP
C WRITE OUT RESULTS OF ANALYSIS
2000 WRITE(LUO,*)' /
      WRITE(LUO,*)'      MAXIMUM DUCTILITY =',RNUMX
      WRITE(LUO,*)'      OCCURS AT TIME =',TM
      WRITE(LUO,*)'      NORMALIZED PRESSURE AT THIS TIME =',FM
      WRITE(LUO,*)' /
      WRITE(LUO,*)'      NATURAL PERIOD =',TN
      WRITE(LUO,*)'      LOAD DURATION =',TD
      WRITE(LUO,*)'      TIME INCREMENT =',TINC
      WRITE(LUO,*)' /
      WRITE(6,*)' COMPLETE HISTORY? (Y/N):'
      CALL READC(IANS,0,0)
      WRITE(6,*)' /
      IF(IANS.EQ.INQ)RETURN
      WRITE(LUO,*)' /
      WRITE(LUO,*)'      NOTE: RESPONSES ARE NORMALIZED:'
      WRITE(LUO,*)' /
      WRITE(LUO,*)'      TIME          DISP          VEL          ACC
      T=0.0-TINC
      DO 2500 I=1,JJ
      T=T+TINC
2500 WRITE(LUO,2510)T,RNU(I),RNUD(I),RNUDD(I)
2510 FORMAT(2(2X,F10.5),2(2X,F10.5))
      WRITE(LUO,*)' /
      RETURN
      END

```

```

C      SUBROUTINE PRESS(P,NT,NP,TD,JJ,TINC,SI,FT)
C
C      SUB FOR COMPUTING NORMALIZED PRESSURE AT A GIVEN TIME STEP
C
C      IMPLICIT INTEGER*2(I-N,*)
C      DIMENSION P(NT)
C
C      SI = REAL TIME FOR THIS STEP
C      SID = NORMALIZED TIME AT END OF DURATION
C      FT = NORMALIZED PRESSURE AT GIVEN TIME
C      TINC = TIME INCREMENT
C      DELTT = TIME INCREMENT BASED ON NUMBER OF PRESSURE STATIONS
C
C      SI=TINC*FLOAT(JJ-1)
C      IF TIME IS BEYOND POSITIVE DURATION, SET PRESSURE = 0
C      IF(SI.LT.TD)GO TO 500
C      FT=0.0
C      RETURN
C      FIND PRESSURE STATION ON EITHER SIDE OF GIVEN TIME
500  DELTT=TD/FLOAT(NP-1)
C      IST1=INT2(SI/DELTT)+1
C      ST1=FLOAT(IST1)
C      ST2=ST1+1.0
C      IST2=IST1+1
C      P11=P(IST1)
C      P12=P(IST2)
C      TST1=(ST1-1.0)*DELTT
C      TST2=TST1+DELTT
C      INTERPOLATE TO FIND PRESSURE THIS TIME STEP
C      FT=(P11-P12)*(SI-TST2)/(TST1-TST2)+P12
C      RETURN
C      END

```



```

SUBROUTINE DISPOP(LUO,JOP,LFUNC,W,PKT,TD,TA,R,HOBK,TN,RMX,
1  DPT,P,NT,NP,PKT,TITLE,BT,TI1,TI2,TOL,NP)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*2 IFU(3)
INTEGER*1 TITLE(72)
DIMENSION P(NT)
DATA INO/'N '//,IFU/'S ','T ','X '//

C
C  DISPLAY DATA
C
WRITE(LUO,*)' '
WRITE(LUO,2010)(TITLE(I),I=1,72)
2010 FORMAT(1X,72A1)
WRITE(LUO,*)' '
WRITE(LUO,*)'      NUMERICAL PARAMETERS:'
WRITE(LUO,*)'      BETA = ',BT
WRITE(LUO,*)'      INTEGRATION INTERVAL =',TI1,' OF PERIOD'
WRITE(LUO,*)'      INTEGRATION INTERVAL =',TI2,' OF DURATION'
WRITE(LUO,*)'      TOLERANCE =',TOL
WRITE(LUO,*)'      NUMBER OF PRESSURE STATIONS =',NP
WRITE(LUO,*)' '
WRITE(LUO,*)'      LOAD DESCRIPTION:'
IF(LFUNC.EQ.IFU(1))GO TO 2050
IF(LFUNC.EQ.IFU(2))GO TO 2100
GO TO 2200
2050 WRITE(LUO,*)'      WEAPON (KT)=' ,W
2100 WRITE(LUO,*)'      PEAK OVERPRESSURE =',PKT
WRITE(LUO,*)'      POSITIVE PHASE DURATION =',TD
IF(LFUNC.EQ.IFU(2))GO TO 2200
WRITE(LUO,*)'      TIME OF ARRIVAL =',TA
WRITE(LUO,*)'      RANGE (KFEET) =',R
WRITE(LUO,*)'      HEIGHT OF BURST (KFEET) =',HOBK
IF(JOP.EQ.5)GO TO 2250
2200 WRITE(LUO,*)' '
WRITE(LUO,*)'      STRUCTURE DESCRIPTION:'
WRITE(LUO,*)'      NATURAL PERIOD =',TN
FREQ=1.0/TN
WRITE(LUO,*)'      FREQUENCY =',FREQ
WRITE(LUO,*)'      PEAK RESISTANCE =',RMX
2250 WRITE(LUO,*)' '
WRITE(6,*)' PRESSURE-TIME HISTORY? (Y/N)'
CALL READC(IANS,0,0)
WRITE(6,*)' '
IF(IANS.EQ.INO)RETURN
T=0.0-DPT
WRITE(LUO,*)' '
WRITE(LUO,*)'      TIME      PRESSURE      NORMALIZED'
WRITE(LUO,*)' '
DO 2300 I=1,NP
PTPKT=P(I)*PKT
T=T+DPT
2300 WRITE(LUO,2310)T,PTPKT,P(I)
2310 FORMAT(3(2X,F10.4))
RETURN
END

```

```

SUBROUTINE LOADOP(LUO,JOP,LFUNC,W,PKT,TD,TA,R,HOBK,DPT,
1 P,NT,NP)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*2 IFU(3)
DIMENSION P(NT)
DATA IFU/'S ','T ','X '//
C
C C LOADING FUNCTION
C
WRITE(6,*)' SELECT SPEICHER-BRODE, TRIANGULAR,',
1 ' OR EXIT: (S,T,X)'
CALL READC(LFUNC,0,0)
WRITE(6,*)' '
DO 3100 I=1,3
IF(LFUNC.EQ.IFU(I))IFUOP=I
3100 CONTINUE
GO TO(3200,3300,3500),IFUOP
3200 WRITE(6,*)' ENTER WEAPON(KT):'
READ(5,*)W
WRITE(6,*)' ENTER PEAK OVERPRESSURE:'
READ(5,*)PKT
WRITE(6,*)' ENTER HEIGHT OF BURST(KFEET):'
READ(5,*)HOBK
CALL BRODEF(P,TD,DPT,W,PKT,NT,NP,HOBK,R,TA)
TD=TD/1000.0
TA=TA/1000.0
DPT=DPT/1000.0
GO TO 3400
3300 WRITE(6,*)' ENTER PEAK OVERPRESSURE:'
READ(5,*)PKT
WRITE(6,*)' ENTER DURATION:'
READ(5,*)TD
CALL BIGGS(P,NT,NP,TD,DPT,PKT)
3400 READ(5,3410)IDUMMY
3410 FORMAT(A2)
3500 RETURN
END

```

```

C$TITLE  FILED IN BRODEP
SUBROUTINE BRODEP(PEST, DP, DT, W, P, NPTS,NP,HOBK,R,TA)
IMPLICIT INTEGER *2(I-N,*)
DOUBLE PRECISION XP,YP,DPP

C
C
C      DIMENSION PEST(NPTS)
C
C  TA ARRIVAL TIME (MSEC)
C  RANGE IN KFEET
C
C  DP POSITIVE PHASE DUR. (MSEC)
C  DT INCREMENT BETWEEN PRESSURE STATIONS
C      IONE = 0
C      W13 = W**(1./3.)
C      YP = HOBK/W13
C      DTT = DT/W13
C
C      XP = ((1.58 * 2. * W / P) ** (1. / 3.))/W13
10 CALL FT(XP,YP,DTT,PEST(1),DPP,IONE,NPTS,NP,TA)
   IF (ABS(PEST(1)/P-1.) .LE. 5.E - 5) GO TO 20
   CALL FT(XP*1.00001,YP,DTT,EST,DPP,IONE,NPTS,NP,TA)
   XP = XP + (PEST(1) - P) * 0.00001 * XP / (PEST(1) - EST)
   GO TO 10
20 R = XP*W13
   IONE=1
   CALL FT(XP,YP,DTT,PEST,DPP,IONE,NPTS,NP,TA)
   DP = DPP*W13
   TA = TA*W13
C  NOTE - REDEFINITION OF DT BELOW - LKG 7/83
C      DT=DTT*W13
C
C
C      RETURN
C      END

```

```

C$TITLE          FILED IN PT
                  SUBROUTINE PT(X,Y,DTT,P,DP,IP,NPT,NP,TAS)
C
C  THIS IS AN IMPLEMENTATION OF THE SPEICHER AND BRODE
C  OCT 1981 P(T,X,Y) NUC, HISTORY
C  REF.  PSR NOTE 385 WITH MOD FOR P ABOVE 10000 PSI
C  WALKER NOV.17,1982
C  INPUT PARAMETERS
C  X = RANGE (KFT/W**1/3)
C  Y = HOB (KRT/W**1/3)
C  T = TIME AFTER TIME OF ARRIVAL (MSEC)
C  IP = 0 FOR PEAK PRESSURE ONLY
C    DTT = TIME STEP SCALED (MSEC/W**1/3)
C
C  OUTPUT PARAMETERS
C
C  P = PRESSURE*TT(PSI)
C  DP = POSITIVE PHASE DURATION (MSEC)
C  ***NOTE T IS CHANGE IN THIS ROUTINE.
C    IMPLICIT INTEGER*2 (I-N,*)
C    IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C    REAL P, DTT, TAS
C    DIMENSION P(NPT)
C
C    XLEAST=1.E-4
C    YLEAST=1.E-4
C    ZLEAST=1.E-4
C    ZMOST=100.
C    IF(X.LT.XLEAST) X=XLEAST
C    IF(Y.LT.YLEAST) Y=YLEAST
C    R=DSQRT(X**2+Y**2)
C    Z=Y/X
C    IF(Z.LT.ZLEAST) Z=ZLEAST
C    IF(Z.GT.ZMOST) Z=ZMOST
C    CALL PPEAK(X,Y,R,Z,DELTAP)
C    P(1) = DELTAP
C    IF(IP.EQ.0) RETURN
C    XM=170.*Y/(1.+337.*Y**.25)+.914*Y**2.5
C    U=(.543-21.8*R+386.*R**2+2383.*R**3)*R**8
C    UD=2.99E-14-(1.91E-10*R**2)+(1.032E-6*R**4)-(4.43E-6*R**6)+
C    & (1.028+(2.087*R)+(2.69*R**2))*R**8
C    U=U/UD
C    TA=U
C    IF(X.LT.XM)GO TO 200
C    W=(1.086-34.605*R+486.3*R**2+2383.*R**3)*R**8
C    WD=3.0137E-13-(1.2128E-9*R**2)+(4.128E-6*R**4)-(1.116E-5*R**6)+
C    & (1.632+2.629*R+2.69*R**2)*R**8
C    W=W/WD
C    TA=(U*XM/X)+(W*(1.-XM/X))
200  CONTINUE
C    S = 1.-1.1E10*(Y**7)/(1.+1.1E10*Y**7)-(2.441E-8*Y*Y/
C    & (1.+9.E10*Y**7))*(1./(4.41E-11+X**10))
C    F = (.01477*(TA**.75)/(1.+0.05836*TA)+7.402E-5*(TA**2.5)/
C    & (1.+1.429E-8*TA**4.75)-.216)*S + .7076-3.077E-5*TA*TA*TA/
C    & (1.+4.367E-5*TA*TA*TA)
C    G = 10.+(77.58-64.99*(TA**.125)/(1.+0.04348*DSQRT(TA)))*S

```

```

      H = 2.753+.05601*TA/(1.+1.473E-9*TA**5)+(.01769*TA/
&      (1.+3.207E-10*TA**4.25)-.03209*(TA**1.25)/(1.+9.914E-8*
&      TA**4)-1.6)*S
      DP = ((1640700.+24629.*TA+416.15*TA*TA)/(10880.+619.76*TA+TA*TA))*
&      (.4+.001204*(TA**1.5)/(1.+0.001559*TA**1.5)+(.0426+.5486*
&      (TA**1.25)/(1.+0.00357*TA**1.5))*S)
C***
C  NOTE MODIFICATION BELOW -
C  COMPUTE TIME STEP BY DIVIDING THE POSITIVE PHASE DURATION
C  BY THE NUMBER OF DESIRED TIME STEPS
C***
      DTT=DP/FLOAT(NP-1)
      DO 500 I = 1,NP
      T = TA+(DTT*(I-1))
      B = (F*(TA/T)**G+(1.-F)*(TA/T)**H)*(1.-(T-TA)/DP)
      IF (X.LT.XM .OR. Y.GT.0.38) GO TO 1000
      XE = 3.039*Y/(1.+6.7*Y)
      E = DABS((X-XM)/(XE-XM))
      IF (E.GT.50.)E=50.
      D = .23+583000.*Y*Y/(26667.+1000000.*Y*Y)+.27*E+(.5-583000.*Y*Y/
&      (26667.+1000000.*Y*Y))*E**5
      A = (D-1.)*(1.-(E**20)/(1.+E**20))
      DT = 474.2*Y*(X-XM)**1.25
      IF(DT.LT.1.E-4) DT=1.E-4
      GA = (T-TA)/DT
      IF(GA.GT.400.) GA=400.
      V = 1.+(3.28E11*(Y**6)/(1.+1.5E12*Y**6.75))*(GA*GA*GA/
&      (6.13+GA*GA*GA))*(1./(1.+9.23*E*E))
      C = ((1.04-240.9*(X**4)/(1.+231.7*X**4))*(GA**7)/((1.+9.23*
&      (GA**8.5)*(1+A)))*(1.-(T-TA)/DP)**8)*2.3E13*(Y**9)/(1.+
&      2.3E13*Y**9)
      P(I) = DELTAP*(1.+A)*(B*V+C)
      GO TO 495
1000  CONTINUE
      P(I) = DELTAP*B
C***
C  NOTE MODIFICATION BELOW -
C  NORMALIZE ALL PRESSURES BY DIVIDING BY PEAK PRESSURE
C***
495  P(I)=P(I)/DELTAP
500  CONTINUE
      TAS = TA
      RETURN
      END

```

```

C*TITLE      FILED IN PPEAK
              SUBROUTINE PPEAK(X,Y,R,Z,DELTA P)
C
C SUB FOR PEAK OVERPRESSURE BY SPEICHER AND BRODE, SEPT. 1980
C MOD BY WALKER FROM MOD BY SPIECHER AND BRODE MARCH 1981
C RANGE TO 0.1 PSI
C
C INPUT PARAMETERS
C X=RANGE (KFT/KT**1/3)
C Y=HOB (KFT/KT**1/3)
C R=SQRT(X**2+Y**2) (KFT/KT**1/3)
C Z=Y/X
C OUTPUT
C DELTA P=PEAK PRESSURE (PSI)
C
C IMPLICIT INTEGER*2 (I-N,*)
C IMPLICIT DOUBLE PRECISION (A-H,O-Z)
C
C   A = 1.22-(3.908*Z*Z)/(1.+810.2*Z**5)
C   B = 2.321+((Z**18)/(1.+1.113*Z**18))*6.195-(.03831*Z**17)/
C   & (1.+0.02415*Z**17)+.6692/(1.+4164.*Z**8)
C   C = 4.153-(1.149*Z**18)/(1.+1.641*Z**18)-1.1/(1.+2.771*Z**2.5)
C   D = -4.166+(25.76*Z**1.75)/(1.+1.382*Z**18)+8.257*Z/(1.+3.219*Z)
C   E = 1.-(.004642*Z**18)/(1.+0.003886*Z**18)
C   F = .6096+(2.879*Z**9.25)/(1.+2.359*Z**14.5)-17.15*Z*Z/
C   & (1.+71.66*Z*Z*Z)
C   G = 1.83+5.361*Z*Z/(1.+3139*Z**6)
C   H = -(64.67*Z**5+.2905)/(1.+441.5*Z**5)-1.389*Z/(1.+49.03*Z**5)+
C   & (8.808*Z**1.5)/(1.+154.5*Z**3.5)+(.0014*R*R/(1.-.158*R+.0486*
C   & R**1.5+.00128*R*R))* (1./(1.+2.*Y))
C
C DELTA P=10.47/(R**A)+B/(R**C)+D*E/(1.+F*R**G)+H
C RETURN
C END

```

```

      SUBROUTINE BIGGS(P,NT,NP,TD,DTT,PKT)
C
C  GENERATE NONDIMENSIONALIZED PRESSURES FOR TRIANGULAR PULSE
      IMPLICIT INTEGER*2(I-N,*)
      DIMENSION P(NT)
      DTT=TD/FLOAT(NP-1)
      P(1)=PKT/PKT
      DO 500 I=1,NT
500  P(I)=P(1)-(I-1)*DTT/TD
      RETURN
      END

```

```

SUBROUTINE NUMOP(LUO,BT,TI1,TI2,TOL,NP)
C
C NUMERICAL PARAMETERS
C
  IMPLICIT INTEGER*2(I-N,#)
  INTEGER*2 NUOP(5)
  DATA NUOP/'B ','I ','T ','N ','X '//
  NOP=5
  NUMOPT=5
  WRITE(6,*)' '
  WRITE(6,*)' SELECT NUMERICAL PARAMETER: (B,I,T,N,X)'
  WRITE(6,*)'      B - BETA'
  WRITE(6,*)'      I - INTEGRATION INCREMENT'
  WRITE(6,*)'      T - TOLERANCE'
  WRITE(6,*)'      N - NUMBER OF PRESSURE STATIONS'
  WRITE(6,*)'      X - EXIT'
  WRITE(6,*)' '
  CALL READC(IOPT,0,0)
  WRITE(6,*)' '
  NUMOPT=5
    DO 10 I=1,NOP
10   IF(IOPT.EQ.NUOP(I))NUMOPT=I
    GO TO(100,200,300,400,500),NUMOPT
C
100  WRITE(6,*)' ENTER BETA: (LINEAR ACCELERATION = 0.16667)'
    READ(5,*)BT
    GO TO 498
200  WRITE(6,*)' ENTER TIME INCREMENT/PERIOD: (TI/TN = 0.01)'
    READ(5,*)TI1
    WRITE(6,*)' ENTER TIME INCREMENT/LOAD DURATION: (TI/TD = 0.01)'
    READ(5,*)TI2
    GO TO 498
300  WRITE(6,*)' ENTER CONVERGENCE TOLERANCE: (TOL. = 1E-3)'
    READ(5,*)TOL
    GO TO 498
400  WRITE(6,*)' ENTER NUMBER OF PRESSURE STATIONS:(MAX. = 250)'
    WRITE(6,*)'      CAUTION: MUST COMPUTE NEW LOAD FUNCTION!'
    READ(5,*)NP
498  READ(5,499)IDUMMY
499  FORMAT(A2)
500  RETURN
    END

```



```

SUBROUTINE OUTOP(LUO)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*2 JDEV(2)
DIMENSION P(250),RNU(1001),RNUD(1001),RNUDD(1001)
DATA JDEV/'T ','P '/
C
C   OUTPUT DEVICE
C
5000  WRITE(6,*)' SELECT TERMINAL OR PRINTER: (T,P)'
      CALL READC(IDEV,0,0)
      WRITE(6,*)' '
      IF(IDEV.EQ.JDEV(1))LUO=6
      IF(IDEV.EQ.JDEV(2))GO TO 5100
      RETURN
5100  LUO=8
      CALL ASSIGN('LP: ',LUO,ISTAT)
      RETURN
      END

```

```

SUBROUTINE PLOTOP(LUO,TITLE,RNU,RNUD,RNUDD,NSTP,
1 P,NT,NP,TD,NNU,TINC,IPASS)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*1 TITLE(72)
INTEGER*2 JPLT(5)
DIMENSION P(NT),RNU(NSTP),RNUD(NSTP),RNUDD(NSTP)
DATA JPLT/'D ','V ','A ','L ','X '//

C
C PLOT RESULTS
C
WRITE(6,*)' SELECT PLOT: (D,V,A,L,X)'
CALL READC(IPLT,0,0)
WRITE(6,*)' '
JPL=5
DO 6100 I=1,4
6100 IF(IPLT.EQ.JPLT(I))JPL=I
IF(JPL.EQ.5)RETURN
IF(IPASS.LT.1)GO TO 6200
IF(IPASS.LT.2.AND.JPL.LE.3)GO TO 6200
DT=TD/(FLOAT(NP-1))*1000.0
TINCP=TINC*1000.0
CALL PLOT(JPL,NSTP,NT,NP,RNU,RNUD,RNUDD,P,TITLE,
1 NNU,TINCP,DT)
RETURN
6200 WRITE(6,*)' ERROR: DATA FOR PLOT NOT AVAILABLE!'
RETURN
END

```

```

      SUBROUTINE PLOT(JPL,NSTP,NT,NP,RNU,RNUD,RNUDD,P,TITLE,
1      NNU,TINC,DELT)
C  SUBROUTINE FOR PLOTTING RESPONSES
      IMPLICIT INTEGER*2(I-N,*)
      INTEGER*1 TITLE(72)
      DIMENSION P(NT),RNU(NSTP),RNUD(NSTP),RNUDD(NSTP)
      DATA K11/11/, K22/22/, K30/30/, K36/36/, TZ/0./
C
      IF(JPL.LT.4)CALL TITLX('TIME (MSEC)',K11)
      CALL NEXTPG
C  WRITE TITLE TO PLOT
      CALL VTSCA(5)
      CALL HIBRN8(1)
      WRITE(6,90)TITLE
90  FORMAT(10X,72A1)
      CALL VTSCA(3)
      CALL OIBRN8(1)
C
      GO TO (100,20),300,400),JPL
100  CALL TITLY1('NORMALIZED DISPLACEMENT (D/XY)',K30)
      CALL QPLOTD(TZ,TINC,RNU,NNU)
      CALL NEXTPG
      RETURN
200  CALL TITLY1('NORMALIZED VELO CITY (V*T/XY) ',K30)
      CALL QPLOTD(TZ,TINC,RNUD,NNU)
      CALL NEXTPG
      RETURN
300  CALL TITLY1('NORMALIZED ACCELERATION (A*T*T/XY) ',K36)
      CALL QPLOTD(TZ,TINC,RNUDD,NNU)
      CALL NEXTPG
      RETURN
400  CALL TITLX('TIME (MSEC)',K11)
      CALL TITLY1('NORMALIZED PRESSURE ',K22)
      CALL QPLOTD(TZ,DELT,P,NP)
      CALL NEXTPG
      RETURN
      END

```

```

SUBROUTINE SETOP(LUO,TN,RMX)
IMPLICIT INTEGER*2(I-N,*)
C
C SET VALUES FOR ANALYSIS
C
WRITE(6,*)' ENTER NATURAL PERIOD:'
READ(5,*)TN
WRITE(6,*)' ENTER PEAK RESISTANCE:'
READ(5,*)RMX
READ(5,10)IDUMMY
10 FORMAT(A2)
RETURN
END

SUBROUTINE TITLOP(TITLE)
IMPLICIT INTEGER*2(I-N,*)
INTEGER*1 TITLE(72)
WRITE(6,*)' ENTER NEW TITLE: (72 CHAR. MAX.)'
READ(5,10)(TITLE(I),I=1,72)
10 FORMAT(72A1)
RETURN
END

```

THIS PAGE IS INTENTIONALLY LEFT BLANK.

APPENDIX B
EXAMPLE COMPUTER SOLUTIONS

#RUN ANAL/ANAL.EXQ

NORMALIZED RESPONSE OF AN SDOF ELASTIC- PLASTIC MODEL

NOTE: DEFAULT UNITS ARE INCHES, POUNDS, AND SEC
UNLESS OTHERWISE SPECIFIED

AVAILABLE OPTIONS

X - EXIT PROGRAM
A - ANALYZE
D - DISPLAY DATA
H - HELP
I - INITIAL PASS
L - LOADING FUNCTION
N - NUMERICAL PARAMETERS
O - OUTPUT DEVICE
P - PLOT
S - SET VALUES FOR ANALYSIS
T - TITLE

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)

T
ENTER NEW TITLE: (72 CHAR. MAX.)
SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)

I
SELECT SPEICHER-BRODE, TRIANGULAR, OR EXIT: (S,T,X)

S
ENTER WEAPON(KT):

20
ENTER PEAK OVERPRESSURE:

25
ENTER HEIGHT OF BURST(KFEET):

8

SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI

NUMERICAL PARAMETERS:

BETA - 0.10007
INTEGRATION INTERVAL - 0.10000E-01 OF PERIOD
INTEGRATION INTERVAL - 0.10000E-01 OF DURATION
TOLERANCE - 0.10000E-02
NUMBER OF PRESSURE STATIONS - 250

LOAD DESCRIPTION:

WEAPON (KT) - 20.000
PEAK OVERPRESSURE - 25.000
POSITIVE PHASE DURATION - 0.41220
TIME OF ARRIVAL - 0.51300
RANGE (KFEET) - 1.7741
HEIGHT OF BURST (KFEET) - 0.00000

PRESSURE-TIME HISTORY? (Y/N)

N

ENTER NATURAL PERIOD:
 V 300
 ENTER PEAK RESISTANCE:
 10 0
 SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)
 A

MAXIMUM DUCTILITY - 0.3813
 OCCURS AT TIME - 0.31800
 NORMALIZED PRESSURE AT THIS TIME - 0.74042E-01

NATURAL PERIOD - 0.30000
 LOAD DURATION - 0.44220
 TIME INCREMENT - 0.30000E-02

COMPLETE HISTORY? (Y/N):
 Y

NOTE: RESPONSES ARE NORMALIZED:

TIME	DISP	VEL	ACC
0.00000	0.00000	0.00000	00.00500
0.00300	0.00480	0.07210	95.88201
0.00600	0.01935	1.91400	92.03000
0.00900	0.04307	2.82375	80.18823
0.01200	0.07570	3.60715	85.40127
0.01500	0.11000	4.53233	81.54372
0.01800	0.10022	5.32082	77.35503
0.02100	0.22328	0.87031	72.04201
0.02400	0.20703	0.78401	68.31834
0.02700	0.35881	7.44307	63.49318
0.03000	0.43034	8.05357	58.48018
0.03300	0.51071	8.61250	53.31572
0.03600	0.60842	9.11013	47.99400
0.03900	0.70102	9.57180	42.54002
0.04200	0.70007	9.90040	36.97874
0.04500	0.90112	10.31091	31.32243
0.04800	1.00570	10.50600	25.81088
0.05100	1.11203	10.84702	24.26700
0.05400	1.22250	11.08217	22.76250
0.05700	1.33453	11.30240	21.30100
0.06000	1.44850	11.50041	19.88410
0.06300	1.56405	11.70037	18.50000
0.06600	1.68255	11.87876	17.10077
0.06900	1.80210	12.04300	15.80000
0.07200	1.92330	12.19034	14.60062
0.07500	2.04600	12.33020	13.37084
0.07800	2.17000	12.46405	12.18023
0.08100	2.29531	12.58003	11.01003
0.08400	2.42104	12.68453	9.88327
0.08700	2.54800	12.77784	8.77844
0.09000	2.67710	12.86025	7.70302
0.09300	2.80013	12.93205	6.65583
0.09600	2.93577	12.99350	5.63324
0.09900	3.06507	13.04485	4.63750
0.10200	3.10003	13.08037	3.66507

0.10800	3.52700	13.11820	2.71724
0.10800	3.45800	13.14083	1.70210
0.11100	3.50045	13.15424	0.88024
0.11400	3.72202	13.15872	0.00003
0.11700	3.85350	13.15448	-0.85453
0.12000	3.98508	13.14173	-1.00551
0.12300	4.11040	13.12007	-2.51789
0.12600	4.24747	13.09147	-3.32178
0.12900	4.37820	13.05432	-4.10670
0.13200	4.50853	13.00912	-4.87475
0.13500	4.63837	12.95091	-5.62636
0.13800	4.76764	12.89098	-6.36038
0.14100	4.89628	12.82978	-7.07901
0.14400	5.02421	12.75547	-7.78268
0.14700	5.15137	12.67421	-8.47001
0.15000	5.27768	12.58613	-9.14413
0.15300	5.40307	12.49130	-9.80402
0.15600	5.52748	12.39012	-10.44978
0.15900	5.65085	12.28240	-11.08201
0.16200	5.77311	12.16854	-11.70179
0.16500	5.89420	12.04840	-12.30880
0.16800	6.01400	11.92243	-12.90323
0.17100	6.13263	11.79048	-13.48611
0.17400	6.24985	11.65277	-14.05756
0.17700	6.36567	11.50930	-14.61708
0.18000	6.48002	11.36048	-15.16507
0.18300	6.59280	11.20612	-15.70450
0.18600	6.70412	11.04644	-16.23102
0.18900	6.81377	10.88154	-16.74944
0.19200	6.92174	10.71150	-17.25739
0.19500	7.02798	10.53644	-17.75525
0.19800	7.13245	10.35644	-18.24373
0.20100	7.23580	10.17101	-18.72333
0.20400	7.33587	9.98202	-19.19300
0.20700	7.43472	9.78778	-19.65533
0.21000	7.53101	9.58890	-20.10864
0.21300	7.62648	9.38505	-20.55363
0.21600	7.71931	9.17793	-20.99013
0.21900	7.81003	8.96588	-21.41898
0.22200	7.89861	8.74959	-21.84020
0.22500	7.98501	8.52912	-22.25343
0.22800	8.06918	8.30455	-22.65948
0.23100	8.15108	8.07596	-23.05852
0.23400	8.23088	7.84342	-23.45009
0.23700	8.30794	7.60699	-23.83485
0.24000	8.38281	7.36676	-24.21307
0.24300	8.45520	7.12277	-24.58446
0.24600	8.52525	6.87510	-24.94934
0.24900	8.59275	6.62381	-25.30811
0.25200	8.65772	6.36897	-25.66061
0.25500	8.72012	6.11003	-26.00687
0.25800	8.77992	5.84880	-26.34740
0.26100	8.83709	5.58371	-26.68219
0.26400	8.89158	5.31524	-27.01100
0.26700	8.94338	5.04352	-27.33444
0.27000	8.99244	4.76858	-27.65260
0.27300	9.03874	4.49049	-27.96564

0 27000	0 08224	4 20031	-20 27242
0 27000	0 12292	3 02507	-20 57483
0 28200	0 10073	3 03784	-20 07199
0 28500	0 19506	3 34700	-20 10420
0 28800	0 22708	3 05457	-20 45198
0 29100	0 25075	2 75864	-20 73466
0 29400	0 20284	2 45900	-30 01270
0 29700	0 30593	2 15841	-30 20044
0 30000	0 32000	1 05420	-30 55500
0 30300	0 34301	1 54732	-30 02034
0 30600	0 35604	1 23781	-31 00080
0 30900	0 30776	0 02572	-31 33734
0 31200	0 37544	0 01109	-31 50930
0 31500	0 37097	0 20305	-31 83755
0 31800	0 38131	-0 02564	-32 08189
0 32100	0 37945	-0 34766	-32 32207

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)
U

SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI

NUMERICAL PARAMETERS.

BETA - 0.10007
 INTEGRATION INTERVAL - 0.10000E-01 OF PERIOD
 INTEGRATION INTERVAL - 0.10000E-01 OF DURATION
 TOLERANCE - 0.10000E-02
 NUMBER OF PRESSURE STATIONS - 250

LOAD DESCRIPTION:

WEAPON (KT) - 20.000
 PEAK OVERPRESSURE - 25.000
 POSITIVE PHASE DURATION - 0.44229
 TIME OF ARRIVAL - 0.51300
 RANGE (KFEET) - 1.7741
 HEIGHT OF BURST (KFEET) - 0.00000

STRUCTURE DESCRIPTION:

NATURAL PERIOD - 0.30000
 FREQUENCY - 3.3333
 PEAK RESISTANCE - 10.000

PRESSURE-TIME HISTORY? (Y/N)

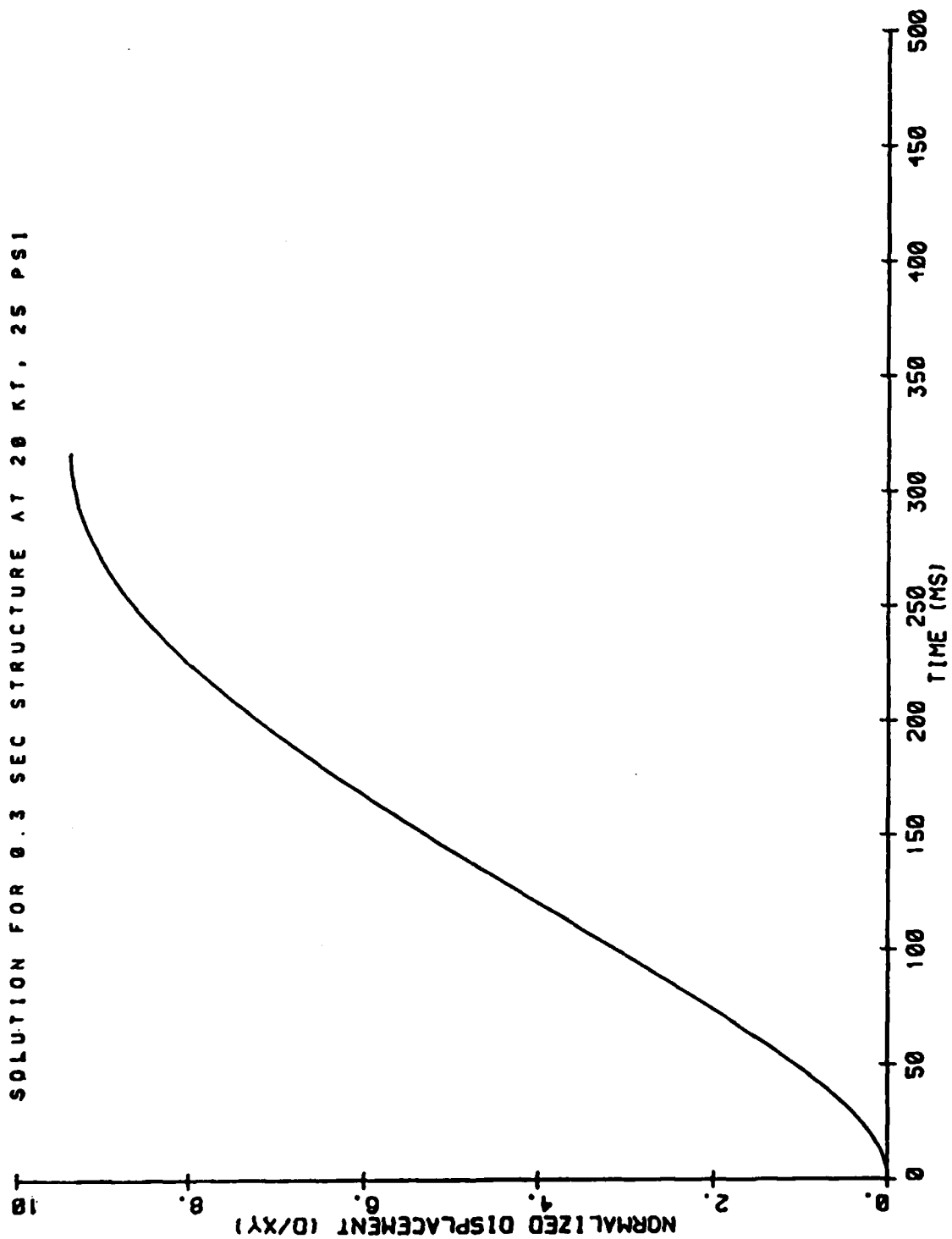
N

SELECT OPTION: (X,A,D,H,I,L,N,O,P,S,T)

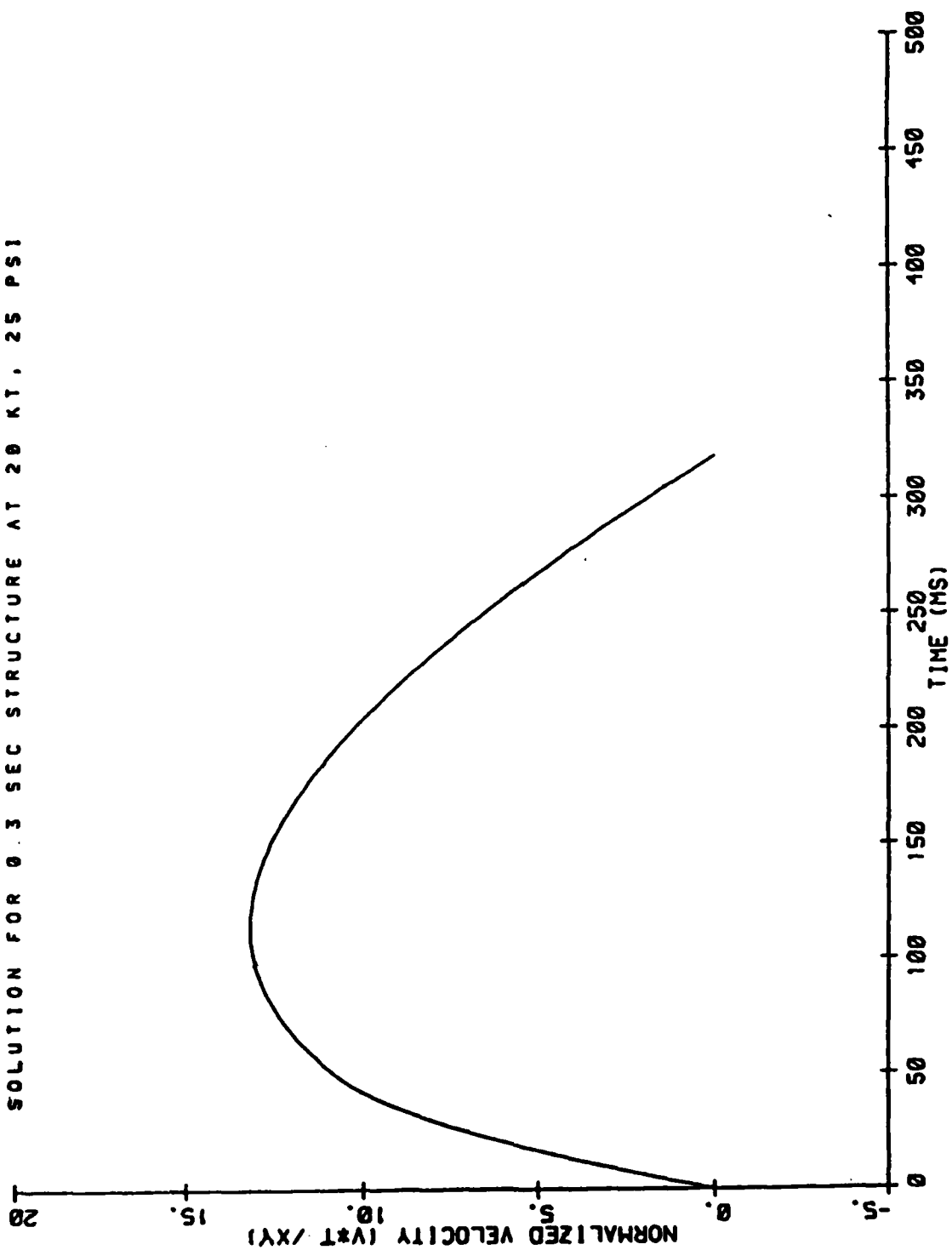
P

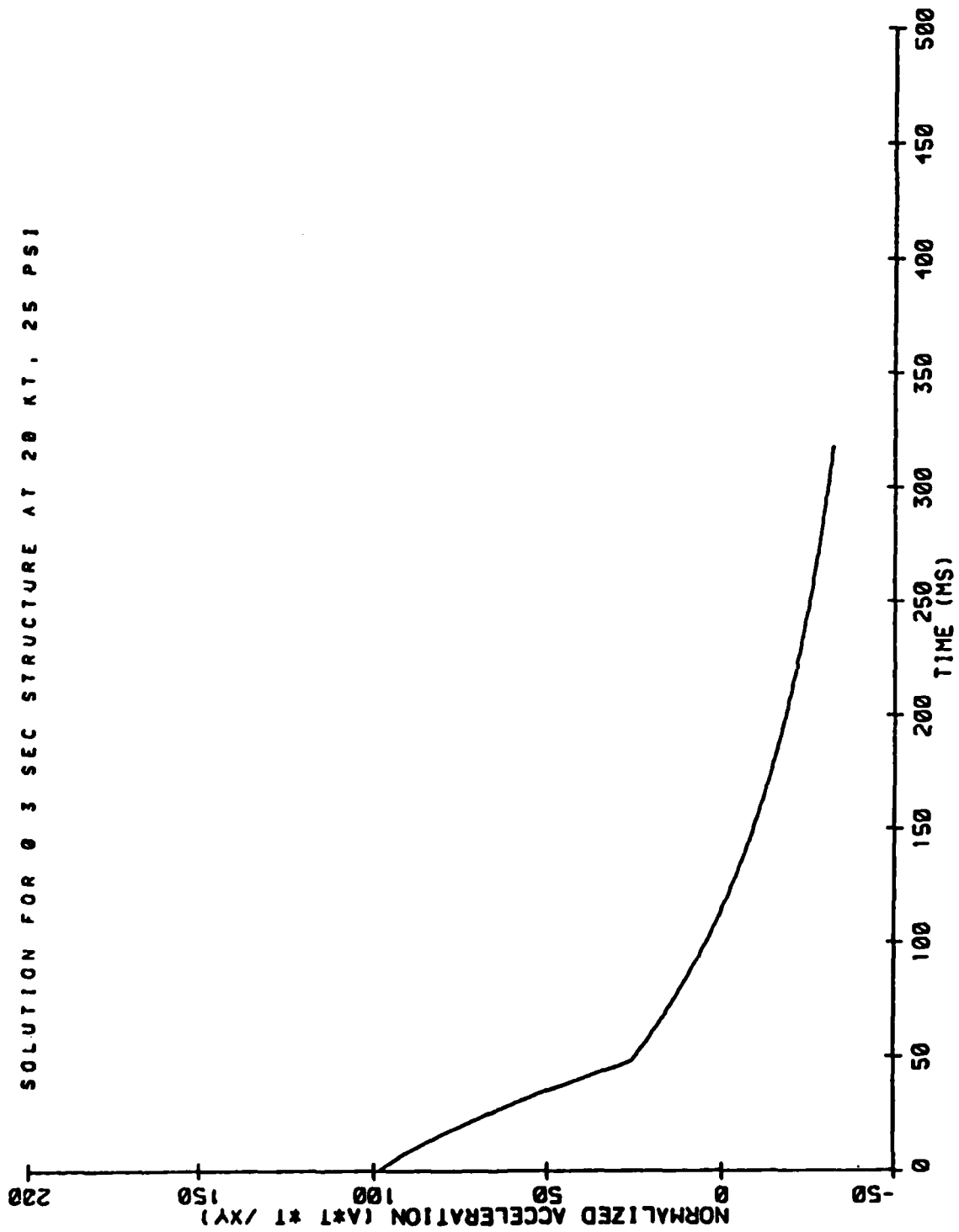
SELECT PLOT (D,V,A,L,X)

SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI

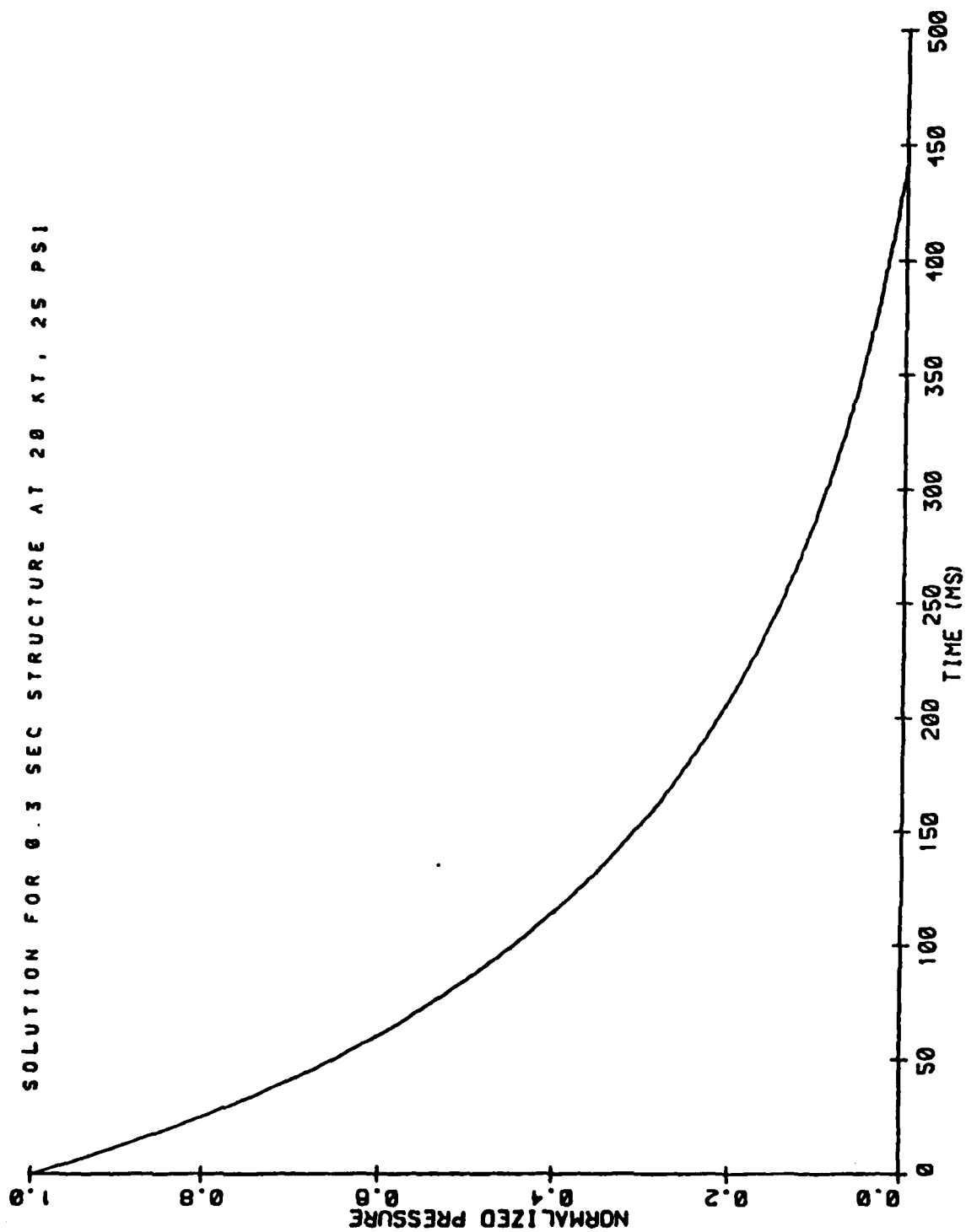


SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI





SOLUTION FOR 0.3 SEC STRUCTURE AT 20 KT, 25 PSI



THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX C
NOTATION

NOTATION

f	Forcing function/maximum force
F	Forcing function
F_1	Maximum force
k	Elastic function
m	Structural mass
P_s	Peak overpressure
r	Structural resistance
r_m	Maximum resistance
t	Time
t_d	Positive phase duration of load
t_m	Time to maximum response
T	Natural period
x	Displacement
\dot{x}	Velocity
\ddot{x}	Acceleration
x_m	Maximum displacement
x_y	Yield or peak elastic displacement
β	Newmark β numerical parameter
Δt	Time increment
η	Normalized displacement
$\dot{\eta}$	Normalized velocity
$\ddot{\eta}$	Normalized acceleration
μ	Ductility
ξ	Normalized time parameter

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Assistant to the Secretary of Defense, Atomic Energy
ATTN: Donald R. Cotter

Director, Defense Advanced Research Projects Agency
ATTN: Technical Library

Director, Federal Emergency Management Agency
ATTN: OMR/Administrative Office

Defense Technical Information Center, Cameron Station
2 cy ATTN: DDAB/Mr. Harry A. Schrecengost, Jr.

Director, Defense Intelligence Agency
ATTN: DT-2, Weapons & Systems Division
DB-4C
Technical Library
Carl Wiehle
3 cy

Director, Defense Nuclear Agency
ATTN: STSI (Archives)
2 cy STTL (Technical Library)
2 cy SPSS
DDST
SPTD/Tom Kennedy
SPSS/Dr. Kent L. Goering
SPSS/MAJ E. Furbee
2 cy TISI
DSNS/MAJ George Flowers
Mr. Cliff McFarland

Director of Defense Research and Engineering
ATTN: Dep Dir, Strategic Systems
Dep Dir, Tactical Warfare

Interservice Nuclear Weapons School
ATTN: Technical Library

Chairman, Department of Defense Explosives Safety Board
ATTN: Dr. Tom Zaker

Director, Joint Strategic Target Planning Staff
ATTN: Science and Technology Information Library
Mr. Bob Rautenberg

Commander, Field Command, Defense Nuclear Agency
ATTN: FCTA-D

Oak Ridge National Laboratory
ATTN: Dr. Conrad Chester

U. S. Department of Energy
ATTN: John Filey/FCMD
L. M. Paradee
John J. Schinkle

DEPARTMENT OF THE ARMY

Commander, U. S. Army Ballistic Missile Defense Systems Command
ATTN: BMDSC-TEN/Noah J. Hurst
BMDSC-HS

DEPARTMENT OF THE ARMY (Continued)

Office, Chief of Engineers, Department of the Army
2 cy ATTN: DAEN-ASI-L
DAEN-MPE-D
DAEN-RDL
DAEN-ZCM/Mr. Swain

Office, Chief of Engineers, Engineers Study Group
ATTN: DAEN-FES/Mr. George H. Orrell

Commander, Harry Diamond Laboratories
ATTN: AMKDO-NP
AMKDO-TI, Technical Library
DELHD-N-EM/Mr. R. Pfeffer

Office, Chief of Research, Development, and Acquisition
ATTN: DAMA-CSM

G. A. Hegemier, UCSD/S3

Commanding Officer, Picatinny Arsenal
ATTN: P. Angelloti

Director, U. S. Army Ballistic Research Laboratories
ATTN: VLD/Steve Zardas
J. H. Keefer
DRDAR-BLT/Mr. C. W. Kitchens
AMXBR-X/Mr. J. J. Meszaros
2 cy Technical Library/Edward Baicy

Commander, U. S. Army Test and Evaluation Command
ATTN: DRSTE-FA/Mr. R. Gallasso

Commandant, U. S. Army Engineer School
ATTN: ATSEN-SY-L

Canadian Forces Liaison Officer, MERADCOM
ATTN: MAJ G. Focsaneanu

Commander, U. S. Army Engineer Division, Huntsville
ATTN: HNDED-CS/Michael M. Dembo
Mr. Robert M. Wamsley
HNDED-CS/Mr. Paul LaHoud
HNDED-CS/Mr. Ron Lein

Commander, U. S. Army Engineer Division, Middle East (REAR)
ATTN: A. Oliver Werner/MEDED-TS

Commander, U. S. Army Engineer District, Omaha
ATTN: Mr. Tim Knight
Mr. James L. Sack

Commander, U. S. Army Engineer Division, Ohio River
ATTN: ORDAS-L/Technical Library

Director, U. S. Army Engineer Waterways Experiment Station
5 cy ATTN: Library

DEPARTMENT OF THE ARMY (Continued)

Commander, U. S. Army Materials and Mechanics
Research Center
ATTN: Technical Library

Commander, White Sands Missile Range
ATTN: STEWS-TE-AN/Mr. Del La Paz

Commander, U. S. Army Tank-Automotive Research
and Development Command
ATTN: DRDTA-NR/Mr. R. Siorek

Commander, U. S. Army Materiel Development and
Readiness Command (DARCOM)
ATTN: Technical Library
2 cy DRCRD-WN

Commander, U. S. Army Missile Command
ATTN: Technical Library
DRCPM-PE/William K. Jann

Commander, U. S. Army Mobility Equipment Research
and Development Center
ATTN: Technical Library

Commander, U. S. Army Nuclear and Chemical Agency
2 cy ATTN: Technical Library
MONA-WE
MONA-WE/COL Lowrey

Commander, U. S. Army Armament Command,
Rock Island Arsenal
ATTN: Technical Library

DEPARTMENT OF THE NAVY

Chief of Naval Operations, Department of the Navy
ATTN: OP-985F

Officer-in-Charge, Civil Engineering Laboratory,
Naval Construction Battalion Center
ATTN: Mr. R. J. Odello
W. A. Keenan
R. Murtha
Technical Library

Commander, Naval Facilities Engineering Command
ATTN: Technical Library, Code 0911C

Superintendent, U. S. Naval Postgraduate School
ATTN: Library, Code 2124

Director, Naval Research Laboratory
ATTN: Code 2027, Technical Library

Commander, Naval Surface Weapons Center
ATTN: Technical Library, Code X211
Code 1224, Navy Nuc Prgms Off

Commander, Naval Weapons Center
ATTN: Code 533, Technical Library

Commander, Naval Weapons Evaluation Facility
ATTN: Technical Library

Chief of Naval Research
ATTN: Technical Library

DEPARTMENT OF THE NAVY (Continued)

Director, Strategic Systems Project Office
ATTN: NSP-43, Technical Library

DEPARTMENT OF THE AIR FORCE

COL Joe Allen, AFOSR

Commander, Air Force Armament and Testing
Laboratory, AFSC
ATTN: Technical Library
DLYV, G. R. Griner
DLYV, R. L. McGuire

AFESC/RDCS
ATTN: LT Tom Hilforty, WN
Dr. Paul Thompson

Air Force Cambridge Research Laboratories, AFSC
ATTN: LW, Dr. Ker Thompson
SUOL AFCL, Research Library

Air Force Institute of Technology
ATTN: Technical Library

AFRCE-MX (DEEC)
ATTN: Mr. George Pace

U. S. Army Corps of Engineers, CEMKPA
ATTN: ED-TS/Mr. Tash Tatsugawa
MXPED-T/Mr. Robert Kelly

Commander, Ballistic Missile Office
ATTN: ENBF/LTC James N. McCallum
ENBF/LT Chris D. Ruff
ENSN/LT Dave Steinfield

Commander, Air Force Weapons Laboratory
ATTN: DEV-S/Dr. T. Ross
SUL, Technical Library
NTE/Dr. M. A. Plamondon

Headquarters, Air Force Systems Command,
Andrews Air Force Base
ATTN: Technical Library

Commander, Armament Division
ATTN: DLODL/Technical Library

Commander, Foreign Technology Division, AFSC
ATTN: TD-BTA Library
Mr. Stan Spring

Commander, Rome Air Development Center, AFSC
ATTN: EMTLD, Documents Library

Space and Missile Systems Organization
ATTN: MMH/Hard Rock Silo Development
MMH/Engineering Division

Commander, Strategic Air Command
ATTN: NRI-STINFO Library

AF Office of Scientific Research
ATTN: Jerry Bieleck

HQ SAC/XPFS
ATTN: MAJ K. L. Mills

APO and FPO

Landa Division, Infrastructure Branch
ATTN: COL Jack Sullivan

USAFE EUROPE/DEXX

ATTN: MAJ H. Dean Bartel

DEPARTMENT OF DEFENSE CONTRACTORS

University of California
ATTN: Joseph A. Smith/L-122

University of Florida
ATTN: Dr. C. Allen Ross

University of Illinois
ATTN: Dr. J. D. Hiltiwanger
Prof. A. H. S. Ang

University of Minnesota
ATTN: Technical Library

University of New Mexico
ATTN: J. W. Jeter
H. L. Schreyer

Northwestern University
ATTN: Dr. Ted Belytchko

Aerospace Corporation
ATTN: Mr. Larry Selzer
Mr. Martin Eskijian
Mr. John Crawford

Agbabian Associates
ATTN: Dr. M. S. Agbabian

Applied Research Inc.
ATTN: Technical Library

Boeing Company
ATTN: Mr. P. A. Krastins

California Research and Technology, Inc.
ATTN: Marvin Ito
Fred M. Sauer

Consulting and Special Engineering Services, Inc.
ATTN: Dr. J. L. Merritt

Electromechanical Systems of New Mexico, Inc.
ATTN: R. A. Shunk

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

General American Transportation Corp.
General American Research Division
ATTN: Library

IIT Research Institute
ATTN: Mr. A. Longinow

Institute for Defense Analyses
ATTN: IDA Librarian, Ruth S. Smith

Kaman Sciences Corporation
ATTN: Gunning Butler, Jr.

Mason & Hanger, Silas Mason Co., Inc.
ATTN: A. T. Papp
Larry L. Skeen

Physics International Company
ATTN: Technical Library

R&D Associates
ATTN: Dr Harold L. Brode
Technical Library
Mr. J. G. Lewis

Science Applications, Inc.
ATTN: Dr. Michael D. McDonnell

Scientific Services, Inc.
ATTN: Dr. B. L. Gabrielsen

Southwest Research Institute
ATTN: Mr. A. B. Wenzel
Mr. Phil Nash

Stanford Research Institute
ATTN: Dr. G. Abrahamson
Jim Gran
Dr. A. Florence

Terra Tek, Inc.
ATTN: Mr. S. J. Green

TRW Defense and Space Systems Group
ATTN: Dr. Richard Cramond
Mr. C. F. Buckley (523/300)
Technical Information Center/S-1
Mr. Norman Lipner
Mr. Paul Chen

Weidlinger Associates, Consulting Engineers
ATTN: Dr. Melvin L. Baron
Dr. J. Isenberg